Sustaining Land Productivity in Developing Countries

United States Department of Agriculture

Office of International Cooperation and Development

in cooperation with

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Bureau for Science and Technology

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FOREWORD

Experience over the past 25 years indicates that agricultural development is the engine that drives economic growth and development in most Third World countries. Given the importance of the agricultural/rural sector, developing countries must not only increase their agricultural productivity but also take steps to assure that these higher productivity levels can be maintained on a continuing basis. This requires, among other things, that these countries meet their people's current needs for food and fiber without damaging the natural resource base on which continuing productivity rests. In fact, the goal should be to enhance that base so as to be able to meet the growing needs of their increasing populations over the longer term.

"Sustainable" agriculture, thus, has become the watchword, not only for developing countries, but also for donor agencies, such as A.I.D. Concern for appropriate land utilization and for protecting the environment and the natural resource base in these countries has become increasingly important for the agricultural development community as well as for the environmentalists. It is a critical element of focus for A.I.D.'s agriculture, rural development and nutrition programs.

To create a better understanding of the complex issues involved, A.I.D.'s Bureau for Science and Technology, in late November 1987, sponsored a seminar on "sustaining land productivity." The aim of the seminar was twofold: First, to increase the awareness of both development professionals and environmental conservationists about the range of natural resource issues that are relevant to sustainable agricultural development. Second, to identify natural resource degradation problems and to begin to identify the actions needed to protect, maintain and improve soil, water and forestry resources to better assure sustained food and fiber production in developing countries.

This publication is a report on that seminar, which consisted of the presentation of four papers by eminent scientists and natural resources managers.

We hope that the publication will be helpful to those who are working toward sustainable agricultural development in the Third World.

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RENEWABLE NATURAL RESOURCES--WHAT IS THERE TO MANAGE?

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I'm sure you are aware that there is sufficient land and water in the world to produce food for a considerably larger population than at present. These resources could likely even support the projected stabilized populations during the next century. So what's all the fuss about?

Think a moment. All the great civilizations throughout history have had good soils as one of their main attributes. The largest expansion of arable land in the industrialized countries took place in the past three centuries through a reduction of forested areas in western and central Europe and the opening up of natural grasslands in North America and the Russian plains. By the end of the 19th century agricultural production was mainly concentrated in regions with favorable soil resources: the vast extent of loess in North America, western and central Europe, the Russian plain, northern China and the southern part of South America; the large alluvial plains and the deltas; the volcanic areas, and the soils developed from basic rocks (Dudal, 1986).

The relevance of soils and their management to world food supplies has never been greater than it is today (Brady, 1986). The land in cereal production increased 3.2% in 10 years (Table 1) with 94% of the increase occurring in the developing world. During this same period cereal production in the developing world increased 62%, and the yield per hectare increases were greater than in developed countries (Table 2). Their actual yields were still only 75% of those of the developed countries. From 1974 to 1984, the world per capita cereal production increased 9%. In North America the per capita cereal production increased 18% but in Africa it dropped 25% (FAO, 1986).

Let me mention one of the reasons we all care. An FAO study about the population-carrying capacities of 117 nations of the world (Table 3) indicated that there were 54 "critical" countries whose potential food capacity at a low level of inputs was less than their populations in 1975 (FAO 1986b). If the inputs are increased to an intermediate level the number of critical countries drops to 24, and even if we could provide high level inputs there are still 13 countries where the land resources are insufficient to meet the food needs of the people living there.

Dr. Dudal of FAO expressed it this way: "The past and existing trends in food and agriculture have led to a situation which, despite notable achievements, is fundamentally unsatisfactory with 450 million people seriously undernourished" (Dudal, 1984). All of us are aware that hunger is a poverty problem, and poverty means you can't afford the necessary inputs to increase productivity, and that means pushing marginal lands, and that means less productivity, and that results in more poverty. It's a rather vicious cycle.

Throughout the world people are seeking ways to coalesce our collective knowledge and bring it to bear in effecting meaningful solutions. I'd like to talk about some of the world's lands. The numbers and proportions I'll mention could just as easily be described from your own personal experiences and knowledge of the diversity in the world. You've seen it time and again. The numbers I'll use come instead, from various FAO and USDA estimates about the status of land resources, especially with regard to agriculture, including lands for grazing livestock and growing trees. I will refer more to arable land than to other classes of land because of the need, that all of us have, to focus on food production. There exists a myriad of complex interactions for which none of us have been able to implement the appropriate actions to drastically alter the tragic dilemma that our world finds itself in this November. But we do have a goal, and each of us shares that goal--in some part.

Over 75% of the land surface is not arable (Table 4). Just think of it, more than three-quarters of everything out there can't be cultivated to crops as we know them. Ten percent of the land is ice covered, another 18% is too steep, and 9% is too shallow. Seventeen percent of the earth's surface is too dry to be arable. Many sand dunes are also unstable, moving from place to place over time. The stony and bouldery lands are also nonarable and in some places they are not even suitable for grazing.

A portion of the land is too cold and has too short a growing season for cultivated crops. Some of the land is, however, satisfactory for long-term forest production and for wildlife preservation. One-fourth of the land can support grasses and shrubs suitable for grazing, but it is not suitable for cultivation. It is nonarable land.

This leaves only about one-fourth (some 22%) of the land with physical conditions favorable for crop production (Table 5). In the developing countries about 37% of the land has a climate favorable for crop production, but only 21% of the land has no fertility limitations (Table 6).

Envision a deep, friable, dark colored soil like those in the cornbelt of the United States. It is estimated that only 3% of the land area of the world is highly productive. That's right, only three percent! Six percent is moderately productive and 13% has a low productive capacity. The potential land base for rainfed crop production in the developing countries is provided in Table 7.

Arable soils range widely in their qualities that affect the rooting and growth of crops. Soil properties are the result of previous interactions of unconsolidated parent materials, climate, vegetation and topography. The oldest soils have been exposed for a few million years and the youngest ones are being deposited by floods or as volcanic ash. Of the soils that might be cultivated, some 1.4 billion hectares are already being cultivated. Worldwide, this is about 40% and the estimated use of land in the developing world in 1975 was only 33% (Table 8).

In the real world, it is extremely unlikely that the entire potentially cultivable area will be used to grow nothing but staple foods. Even for mere subsistence, land is required to grow vegetables and fruit to provide the vitamins and minerals for health. Land is also needed to grow fiber

crops and trees to provide fuelwood and meet other needs. In addition, nonfood cash crops may be grown to earn foreign exchange, or to provide cash for farmers to buy essential manufactured items such as pots and pans, items of furniture, bicycles or carts.

The current physical and chemical processes in soils are mainly controlled by weather. Because soil properties and weather conditions vary from location to location, there are many combinations within the spectrum we call the "arable lands." In arid or semiarid areas, agriculture starts off at a disadvantage (FAO, 1986c). Average climatic conditions are near the threshold for many crops. These areas, therefore, suffer from marginal conditions, as well as increasing seasonal and annual variability in the pattern of rainfall. The effect of climatic variability and the generally low level of inputs used in agriculture is to depress yields, which explains the predicament of these regions with regard to the potential for increased agricultural production.

Some soils have favorable properties for cultivation but the climate is wrong. If they are close enough to sources or supplies of water, the soils are often irrigated. This creates an environment of its own that requires constant monitoring and careful management to avoid degradation. There is a large potential to expand irrigation (Table 9), but considerations other than the physical environment will limit the actual use.

Sloping soils in semiarid areas are subject to serious degradation from erosion by running water. The effect of erosion includes on-site reduction of productivity and off-site damages, such as poorer water quality due to the transported soil particles. Steep slopes and erosion are major constraints in many areas and their influence is compounded where population densities are high. However, slopes that are equally as steep may be successfully utilized if the soils and the climate are favorable. The threat of degradation of our land resources exists everywhere (Table 10).

A significant contribution to planning strategies is a soil resource inventory. One interpretive map is based on a revision of the FAO/UNESCO world soil map and a soil taxonomy legend. Major constraints are represented for use of the soil resources as well as for locating areas that are nonarable. Specific soil features are highlighted--very acid, low exchange capacity, highly erodible and so forth. Resource inventories and their interpretations are appropriate at all scales, from the world to the farmer's field.

Soil-related chemical constraints commonly show up as plant mineral deficiencies such as potassium deficiency. In the acid low fertility soils in tropical America (about 1 billion hectares) it is estimated that more than 60% of the soils have chemical constraints ranging from phosphorus and nitrogen deficiency to aluminum toxicity (Brady, 1986). More than 80% of the oxisols, which are common soils in the tropics, have chemical constraints to crop production.

Overcoming aluminum toxicity with modest amounts of lime is demonstrated by rooting in soil with and without additions of lime. Seventy-two percent of the acid infertile soils in tropical America have this problem.

The fertility requirements for high food production on soils in the tropics in Africa need additional investigations.

Mineralogy is important to the physical behavior of soils as well as affecting their nutrient-supplying capacity. There is a soil mineral called imogolite, a gel-like short-range ordered mineral that has a high exchange capacity, fixes lots of phosphorus, retains a lot of water, and also provides stability to soil structural units. There are many different minerals in soils.

The climate and the soil must be suitable and the technology appropriate before results such as the steep land terraces in the Philippines can occur. This type of technology cannot be transferred to just any old place; it has to go to places where the conditions are similar. Trial-and-error has always been a hard way to make progress.

A rain forest is a finely tuned ecosystem. The trees send down roots deep into the substratum that scavenge nutrients and store them in the biomass. When the trees die, animals and other plants feed quickly and recycle the precious elements. When first cleared, the mellow friable soil releases the nutrients and the shallow rooted recycling of the crops takes place. In humid areas the main problems are the low nutrient retention capacity, aluminum toxicity and low availability of phosphorus, associated with strong leaching. The natural vegetation is forest and these lands are best suited to perennial crops.

One of the great challenges is to develop a viable replacement for the shifting cultivation or "slash and burn" farming systems so common in the uplands of Africa, Latin America and Asia. Some 720 million hectares of forested areas are subject to the "slash and burn" systems. At least 300 million poor people subsist on these systems worldwide. About 45% of Africans are said to be dependent on these systems (Brady, 1986).

Most soils of tropical and subtropical regions cannot be cultivated continuously under traditional, low-input farming. The onset of declining yields is a sign that the farmer should stop cultivating the plot and allow the natural vegetation to reestablish itself (FAO, 1986). Cropping between bush fallow is usually brief as the stored nutrients are rapidly used and productivity starts to decline. Chemical fertilizers have not yet been designed that replace the beneficial effects of forest fallow. We still have much to learn about the ancient ecological rejuvenation processes of tropical forests.

Soil constraints can markedly reduce crop production but management techniques aimed at limiting the reductions can be introduced if the necessary inputs are made available. Some constraints can be dealt with by the farmers through their own efforts if the incentive is given; others require community or government intervention, and others may be irremovable and so thus must be endured (FAO, 1986c).

Will the land succumb to the scorching rays of the sun that retard biological activity in the surface layers and rapidly oxidize a portion of the precious organic matter? Will the driving rain tear apart the fragile

structure and let the sand and clay particles separate? Will the land erode and carry away the best part of its livelihood?

In the semiarid areas, the nutrient deficiency may be as limiting as the shortage of moisture. Poor nutrient supplies can prevent full benefit from the rainfall in the wetter years. In drier years, applied fertilizer may produce little or no response (FAO, 1986c).

Or will this land respond to gentle reasoned care and give rise to intercropping production vastly superior to either crop when grown alone?

A worldwide system of soil classification is a useful means to recognize and identify different kinds of soils. It is a language of soil scientists, but it carries a possibility of far-reaching consequences. Instead of many languages there could be one--at least to communicate our findings.

With one soil taxonomy, we can see the world as sets of interconnected relations. Soil patterns reflect the influence of parent material, vegetation, climate and topography. Colors on maps locate areas having similarities--the temperate regions in blue are not similar to the tropical regions in red. Simple. Important.

Most of the developing countries are located in the tropics or sub-tropics. All too little is known about the soils in these areas and about their management. Research on tropical soils is distressingly lacking. Variability of soils is greater than in the arid and cooler zones. Chemical characteristics of soils of the tropics differ markedly from those of soils of temperate regions.

There is a need to obtain further information on the characteristics of these soils, on their classification and response to management, and people need training to be able to do so. Research is being done to make it easier to transfer agroproduction technology for kinds of soils but it is still a slow process.

In black soils at high elevations, a volcanic tuff separates two layers of ash. What crops are best suited to the cool humid short season climate and the physically stable, high phosphorous fixing soils at 3140 meters above sea level? A brown surface soil over a red mottled subsoil means sandy terrace deposits over weathered tertiary rocks about 80 meters above sea level. If farming systems are evaluated here, how far away should you try to take the results? Is there a lot, or just a little of this kind of soil?

Soil-related research is expensive. There are thousands of kinds of soils. Try to do it right the first time. Understand the purpose of the research and then leverage the results by networking with other interested workers. Soil and site characterization of experimental areas and of experimental stations is a good place to start, or to do second, or perhaps third. But whatever else you do, it's good business to know the resources that are available and those that are considered representative. Good modelling accurately reflects the field conditions.

A detailed soil map doesn't grow more food, or stop erosion, or provide fuelwood, or build highways, or install irrigation systems. But the information properly interpreted can make decisions about the inputs and management a lot more rational and consistent for sustainable natural resource utilization. For example, consider a wet sandy trail that served as an initial road across a high rainfall tropical savanna. What could be more durable and stable than nearly pure quartz sands? But, extremely acid water rises to the surface and the sand can be readily crushed into silt-sized quartz in your fingers. This could be useful information if you are planning the infrastructure for economic development of the area.

When I see a small stack of precious sticks for fuelwood I try to remember that uncooked millet is not very palatable. A chill when you are feverish and ache all over is not pleasant. Pressure for firewood removes the trees and rescinds the slow regenerative processes that had once supported the people. Are the same trees the best to replant or are there others that grow elsewhere that may be better?

As Higgins *et al.* (1982) so succinctly stated, "The next 40 years will constitute a turning period in human history: the period when it will be decided whether populations can be accommodated to national resources without widespread suffering, disruption or degradation of the environment. The outcome concerns not only the potentially critical countries but the whole human race, and it depends on our present actions or omissions."

In the developed countries it is possible to see agricultural production that is fully mechanized, backstopped by the latest scientific reports, in constant communication with the weather, the markets, the buyers, and the shippers. Effective?...indeed. Energy efficient?...strange you should ask that. Even in the developed countries the potential yields are not yet readily achieved! Technology transfer is not magic, it is hard work--but well worth the effort.

Visualize the colorful scene of women hand-threshing and winnowing chaff of a millet harvest in southern India. In contrast are the rows of combines winding over the hills in the Palouse. Optimal production is a relative term, isn't it? Good return for the inputs? Sustainable use of the resources? Efficient, effective utilization of labor, capital, land, water, and technology. Whose concept of "optimal" do we use? Those whose inputs are mainly hand labor--or those whose inputs are mainly high-tech mechanization?

The world can increase food production by: (a) increasing the amount of arable land, (b) increasing the yields per hectare of the plants being grown, and (c) changing the cropping intensity (Brady, 1986). It is estimated that by the year 2000 about one-fifth of the increase of food production will be by increased intensity of land use. Alley cropping with legume trees and food crops is one such way. It also imitates the "slash and burn" forest rejuvenation processes. But we still have a lot to learn about where the system works best, and which plant combinations are suited to which soil and climate conditions.

Labor is still scarce in some areas in the tropics and cattle are the main processors of land productivity. Improved pastures and improved

livestock breeding and management contribute to economic growth. There is still time to experiment with various cropping systems--matching the soil and crop characteristics--to be ready when the priorities change.

Land tenure still looms as a specter for many. And landless tenancy often feeds government programs of land reformation and transmigration. What is an equitable amount of land? Of what quality should it be, or is just the number of hectares a satisfactory measure? Why is it that the fixed rates of fertilizer aren't leading to surpluses for the world market? Sorry, the better lands are already in use.

The world is working hard to have technology transfer become more and more meaningful in the race, the struggle, the desire, to make wise use of the renewable natural resources. We are painfully aware of the imbalance of these resources and the pressures that carry actions far beyond reasonable expectations of sustainable agriculture. The gaps seem so very wide and the prospects frightening (Table 11).

Getting the information out is serious business: books, articles, papers, slide sets and training forums; problem identification, networking, conferences, meetings and one-on-one visits. Here we are in the "information age"--almost drowning in information--and there is still a dichotomy. We have the ability to produce sizeable surpluses that could support more people and do so in an environmentally sound, sustainable way, but we are unable to face up to the requirements of survival on this planet earth.

Increasing yields per hectare is thought to be the major way to increase food (Brady, 1986). Generally, more than 50% of the increases will come this way. Getting more from each kind of soil. Helping out nature is part of the strategy and supplemental irrigation can be used to extend the opportunity to utilize solar radiation.

Industrial development, processing plants, marketing, infrastructures are signs of progress as agriculture and economic growth go hand in hand. Planning for the future is easier when the uncertainties are not related to the physical environment. Scientists can help reduce the uncertainty associated with land resources.

Man can live in harmony with the resources. Man can have health, and quality of life, and esthetics. Each landscape has its possibilities and its constraints. The contoured strips, the grassed waterways, and the small ponds reaching to the far horizon confirm the opportunities to improve. Must we always learn empirically by trial and error--by foolish mistakes? Can we not plan and implement a better world?

There in the sunlight is a statue of a young man. Hear his message. Raise forth your hand. Know that the diversity and abundance of natural renewable resources are mirrored by the people themselves. Feel the sunshine on your upturned face, search out that which will bring to pass the wise use of the resources of the land--the soils, the water, the plants, the animals--but most importantly--the people. You don't really transfer any technology until you get an institutional change that can socialize and implement that technology.

As you gaze at the people who gather around to see and to listen, recall that to implement technology something has to change. Only people can implement. Only people can socialize. But governments must recognize, and hear, and believe, and take appropriate actions.

And look closely at the women. See their faces, peer into their eyes. Without them, progress may be too slow to save thousands of lives. Women are an institution; women may just be the real key to technology transfer in agriculture. Goodness knows men have struggled with it a long time. But it won't just happen, will it? Growth and development and love--all must be nurtured. Know the resources and use them wisely.

People use, and people abuse, resources. It is fortunate that although arable soils are finite and represent a possible limit for mankind, they are also resilient. They will respond to the biotechnologies of the future just as surely as they have sustained mankind all these many years. You are important to that future, because at this point in time you represent "the good hands people" of the Earth.

Conclusions

The physical resource base has a central and vital role in development. 1Past misuse and exploitation have caused considerable degradation of these resources yet they, and the opportunities they present, are the foundation on which viable social-economic systems must be constructed (FAO, 1986a). There is a crucial need to increase the efficiency of present resource utilization while at the same time conserving and where possible, enhancing the productive capacity of the resource base.

The improved utilization of land resources involves correcting many ills including: (FAO, 1986b)

* Use of land for crops for which it is not suited
* Attempted cultivation of sloping lands
* Overexploitation and reduction of necessary fallow periods
* Overstocking and overgrazing
* Clearing of lands requiring protective forest
* Excessive fuelwood removal
* Inappropriate land clearing practices which damage the land

The overriding strategy for improved efficiency is sound land use planning and subsequent implementation of actions to match demand with the potentials of land or produce. There is no magic to effective and sound use of land. The principles of sound land husbandry are known and apply to every part of the world. Countries must systematically assess land

potentials as a basis for guiding investment and selecting the appropriate use. Land use must be adjusted to the pattern of land suitability.

Efforts should be made to break through the resource-illiteracy which widely prevails. Many agricultural and rural development programs fail because the most elementary data on the natural resource base are ignored or are not sufficiently taken into account.

A major step forward can be achieved by putting already available land resource information to work at all levels of decision-making--from the nation to the project to the farm.

According to FAO (1986a) considerable information could be derived immediately from a "balance sheet" approach, evaluating the relationship between present and future demands on the resources and their potentials to respond to those demands (Table 12). These would be the start for national land-use plans identifying broadly defined combinations of land uses needed to sustain the economy. Such plans would guide land-use planning within the country and set priorities for resource development as well as identify areas where maximum response to additional inputs may be obtained. They would also help isolate the major land-use problems and channel national and donor support to specific problem areas within the country.

This "balance sheet" strategy should not detract from a commitment to continued long-term resource assessment activities as a prerequisite to refined land use plans at all levels within a country. There is a clear need for:

* Reliable inventories of the natural resources evaluated in terms of the various potentials for different types of land use,

* Up-to-date land-use information and status or condition of areas, and

* Estimates of the supporting capacities and calculation of production targets based on the integration of resource and land-use information with population projections and economic data (FAO, 1986a).

Education is perhaps the main component of long-term solutions to the many land-husbandry problems. The extension worker is undoubtedly a key participant. Basic education of people is an important cornerstone in improved resource use. Teaching a land ethic and the national objectives of a covenant for land husbandry, particularly conservation, begin early in public education. Education's greatest contribution is probably achieved through its attack on illiteracy, thus the key role of village school teachers.

As summarized by FAO (1986a) after their look at Africa, "There are no easy solutions and no panaceas to the 'land' problem. Each country will have to develop its own package of land and water husbandry measures, with due emphasis on the central importance of land conservation, the development

of human resources, equity, and people's participation. Without attention to these factors, no plan or technical solution stands much chance of success. The necessity of 'knowing what one is dealing with' is perhaps the most important conclusion policymakers could draw from a review of land resources."

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Table 1. World Land in Cereal Production (million ha)[1/]

	1974/75	1984/85
All cereals	703.9	726.7
Rice	137.0	144.6
Wheat	221.8	231.9
Coarse Grains	345.1	350.2

1/ Data from FAO, 1986c.

Table 2. World Cereal Yields (tons/ha)[1/]

	1974/75	1984/85	Average Annual Percent Increase: Developing Countries	Average Annual Percent Increase: Developed Countries
All cereals	1.90	2.48	3.8	2.4
Rice	2.43	3.26	3.6	0.6
Wheat	1.64	2.26	6.1	2.7
Coarse Grains	1.86	2.31	2.4	2.4

1/ Data from FAO, 1986c.

Table 3. Land Use and Population (area in million ha)[1/]

	Developing Countries	Developed Countries	Total World
Land area	7619	5773	13392
Population 1979 (million)	3117	1218	4335
Potentially cultivable	2154	877	3031
% of land area	28	12	22
Presently cultivated	784	677	1461
% of potential	36	77	48

1/ From Dudal, Higgins and Kassam, 1982.

Table 4. Critical Countries[1/]

Countries		Africa	S. America	SE Asia	SW Asia	Central America	Total
Total Countries		51	13	16	16	21	117
	Low	22	--	6	15	11	54
1975	Int.	7	--	1	12	4	24
	High	2	--	1	9	1	13
	Low	29	--	6	15	14	64
2000	Int.	12	--	2	15	7	36
	High	4	--	1	12	2	19

1/ From Figure 4 (page 13), FAO, 1986b.

Table 5. Crop Production Constraints of the Land Area of the World[1/]

Constraint	Area (m ha)	Percentage
Ice covered	1490	10
Too cold	2235	15
Too dry	2533	17
Too steep	2682	18
Too shallow	1341	9
Too wet	596	4
Too poor	745	5
Subtotal	11622	78
Low productive	1937	13
Medium productive	894	6
Highly productive	447	3
Subtotal	3278	22
Total	14900	100

1/ From Table 5 in Buringh, 1982.

Table 6. Climate and Soils (percent of land)[1/]

Region	Suitable Climate	No Fertility Limitations
Africa	53	19
South America	85	20
Southeast Asia	84	36
Southwest Asia	18	8
Central America	64	44
Total	37	21

1/ From Figure 1 (page 5), FAO, 1986b.

Table 7. Potential Land Base for Rainfed Crop Production[1/]

Region	Suitable	Marginal	Unsuitable
Africa	789	231	1858
South America	819	147	804
Southeast Asia	294	226	378
Southwest Asia (Near East)	48	16	613
Central America	74	15	182

1/ From Figure 3, FAO, 1986b.

Table 8. Use of Potentially Cultivable Land (million ha)[1/]

Region	Cultivated in 1975	2000	Cultivable
Africa	168	204	789
South America	124	166	819
Southeast Asia	274	308	297
Near East	69	74	48
Central America	36	41	74

1/ From Figure 9, FAO, 1986b.

Table 9. Expansion or Irrigation (million ha)[1/]

Region	Irrigated in 1980	2000	Potentially Suitable for Irrigation
Africa	3	6	19
Latin America	12	19	44
Southeast Asia	60	98	218
Southwest Asia (Near East)	19	25	29
90 Developing Countries	94	148	310

1/ From Figure 14, FAO, 1986b.

Table 10. Degradation Threat: Losses of Rainfed Cropland[1/]

	Potential Loss of Cropland	
Region	**Million ha**	**%**
Africa	203	16.5
South America	112	10
Southeast Asia	176	36
Southeast Asia (Near East)	13	20
Central America	40	30

Equivalent land area due to decreased productivity if degradation were to go unchecked.

1/ From Figure 2, FAO, 1986b.

Table 11. Estimated Population Carrying Capacity of Lands that are Cultivated[1/]

Region	1975			2000		
	L	I	H	L	I	H
Africa	0.8	3.3	9.6	0.6	2.0	5.7
South America	0.6	2.4	5.8	0.5	1.8	4.3
Southeast Asia	0.7	1.8	3.1	0.8	1.5	2.2
Southwest Asia (Near East)	0.5	0.8	1.3	0.4	0.6	0.8
Central America	0.5	1.4	3.7	0.5	0.9	2.2

1/ Figures show fractions of population that regional lands can support assuming 2/3 cultivated land is used for staple foods. Ratios below 1 are considered to be critical.

Table 12. Projected Land Demand of all Sectors at Year 2010--Low Input Level (million ha)[1/]

Region	Total Extent	Pot. Cul. Rainfed	Land Requirements: Crop Land	Live Stock	Forestry	Total
Mediterranean and North Africa	600	14	20	106	10	136
Sudano-Sahelian Africa	828	118	60	696	88	844
Humid and Sub-humid West Africa	207	99	70	99	22	190
Humid Central Africa	399	282	35	18	257	311
Subhumid and Mountain East Africa	251	77	37	248	43	328
Subhumid and Semiarid Southern Africa	559	230	46	445	198	689
Total	2844	820	269	1611	619	2499

1/ From Table 7.13, FAO, 1986a.

ISSUES OF CONCERN IN LAND USE FOR DEVELOPING COUNTRIES

Sylvan Wittwer

Land comes first in a consideration of life-supporting systems on a global scale, and food production is our most important renewable resource. The determinants of future agricultural production are new technologies, economic incentives and natural resource inputs.

The current world agricultural situation may be summarized as follows (21): During the next decade, the problems will be distribution and utilization of existing production and increases in resource conservation, especially of soil and water. Temporarily at least, the world has learned how to increase agricultural production. Beyond the next decade there will be a need for increased capacity in agricultural output since production per unit land area will otherwise decline from global pollution, soil losses from erosion, sedimentation, overdraft of nonrenewable ground water, possible climatic changes from rising levels of carbon dioxide and other atmospheric gases (today, areas with good agricultural soils tend to also have the best producing climates), salinization of soils, and increases in numbers and demands of people (4,9,22).

The keys to sustained or increased agricultural production include preservation and wise management of the resource base; careful use of genetic engineering; explorations for new crops among the world's existing vegetation; and control of land, water and air degradation and pollution. The current dilemmas and solutions must be viewed, among other approaches, within the social, economic and political framework of our current knowledge and society.

Land Global Habitability

Land is first among earth's life-supporting systems. It is where people live, it is where most food comes from, it is where cattle graze and crops are produced. Most recreational areas are on the land, as is the production of most renewable resources. Land global habitability is receiving a new and justifiable emphasis.

Several global problems are associated with ongoing changes in land surface, and its use. These changes are impacting all nations, especially the developing countries. They include deforestation (estimated to range from 11 to 20 million hectares per year), desertification (two million hectares per year) soil erosion, excess tillage, salinization, a lack of drainage, aluminum toxicity, and accumulations of heavy metals and other toxic substances.

Only rough estimates of total areas affected are available. For example, in South America it is believed that one-third to one-half of the irrigated lands are affected by salinization. Included also are changes in tillage practices, marginal soils, conversion of noncropland, and management

of range lands and forests. Neither the magnitude nor the rate of these changes is known, yet volumes have been published on the presumed future hazards of some of the above practices and phenomena on life-supporting systems and food production.

Estimates of annual losses from soil erosion range from four billion tons annually in the United States (mostly from row cropped land) to 25 billion tons globally. Although soil erosion is considered by most conservationists as an unmitigated evil, and volumes have been written on it, quantitative data on rates for different ecological environments, land uses and farming systems are not known for most parts of the world, especially the agricultural developing nations. Estimates of present rates of global soil erosion for some regions vary by several orders of magnitude.

Effects of soil erosion on crop or plant production are equally controversial (3,4,8,15,17). There is a great need for strengthening the data base with regard to erosion-induced effects and other cause-and-effect relationships on crop productivity. Globally it has been estimated we are annually losing eight million hectares of land from nonagricultural conversions, three million from soil erosion, and one million to desertification and toxification.

Soil erosion, both from wind and water, is not a new phenomenon. As a natural process it has historically formed the most fertile valleys and flood plains on earth. These reservoirs of productive soils, formed over millions of years of weathering, erosion, and deposition cycles, have supported the great civilizations of the past and the present world population, and will supply food, feed and fiber for generations yet unborn. These both natural and creative processes displace billions of tons of soil each year, and they have been going on for a long time. Of concern is that they are being greatly increased, perhaps two- to five-fold, by man's intervention. Vast areas of once productive lands are now unproductive and have become wastelands.

Soil erosion has become an emotional issue, and scientific credibility is at stake. Many scientists are conservationists, otherwise well-meaning, have learned the potential lesson that frightening the public gets results--often meaning increased support for their special research interests (19).

Major shifts in cropping patterns for many developing as well as agriculturally developed countries have occurred during the past two decades. No soil management technology has moved more rapidly for conservation of soil, water, energy and organic matters than has zero, reduced, and conservation tillage. It is a global phenomenon and could be called a "reduced tillage revolution." Combined with allelopathic properties of plant residues, conservation tillage or no-till, and/or alley cropping and mulch farming when coupled with the rolling injector planter are beginning to provide the long-sought-after means for continuous cropping of many of the shallow, fragile and easily erodible soils in the lowland and humid tropics. Plastic soil-mulching of large areas devoted to the production of major agricultural crops (such as cotton in China) is changing the characteristics of land surfaces, soil temperatures and rates of erosion.

Seldom has such a totally new set of competitive forces been unleased on soil and land resources as is now occurring. The current global over-production of most agricultural commodities provides a marvelous opportunity to take corrective measures for soil and water conservation (9,20). There is an increasing support for more effective management of natural resources. Perhaps it is opportune to begin to devote highly erosive, fragile and shallow cropland to other uses such as soil-improving crops, grazing, wood fuel production, reserves for wildlife and for recreation. Consideration should also be given to reclaiming the millions of hectares of land once agriculturally productive but now neglected for centuries because of salinization, toxic materials, poor drainage or reduced fertility.

Specific Issues of Land Use in Developing Countries

Traditionally the productivity of land has been sustained, and at times increased significantly over centuries past, by many different technologies some of which are considered ecologically stable. Minimal mechanical soil disturbance has been an integral part of traditional farming in the tropics (11,13,14). It is described by such terms as "shifting cultivation," "bush fallow rotation," "slash and burn" and "milpa farming (2,16,25)." The practice is one of minimal soil manipulation coupled with vegetative cover to avoid erosion and irreversible soil quality degradation.

The challenge and issue for land use in developing countries are not the replacement of traditional farming or soil culture systems with those that utilize modern heavy equipment, fertilizers and pesticides. Rather than replacing that which is currently subsistence but ecologically sound agriculture, the approach should be to improve productivity of the traditional by appropriate inputs of modern technology. The goal should be improved productivity and land-use intensity. At the same time erosion should be curtailed, a favorable soil structure maintained, coupled with minimal use of agrochemicals and other fossil fuel-based inputs and high levels of production per unit land area. The remains as the supreme challenge for soil management in developing countries.

Traditional agricultural practices--bush fallow, mixed cropping, shifting cultivation, slash and burn, milpa farming--have been compatible with the ecological environment. Stability and ecological compatibility of such systems depend on low population pressure; improvement in soil structure by roots; erosion control through litter or other mulch; a continuous canopy; nutrient contributions through recycling; ash from burning; deep-rooted perennials and trees; and pest control through simultaneously growing a wide range of plant species.

Attempts to replace traditional systems with disregard to economical stability have not been successful. Invariably they have resulted in accelerated soil erosion, drought stress and nutrient imbalance. The rationale is that a continuation of traditional shifting cultivation techniques will not support the exploding population of most agriculturally developing nations especially those in the tropics. Technologies must be developed to continually crop soils in the tropics. This constitutes the greatest challenge in their management. The other approach is to improve traditional agriculture technologies in developing countries rather than

replace them by systems developed elsewhere. Promising alternatives follow, all of which are a part of an ongoing tillage revolution (12,13).

Mulch Farming. The value of crop residues as soil mulches to moderate harsh climates is well known. Crop residue mulches have long been utilized to improve agricultural productivity. Mulches control weeds and soil erosion, increase the soil organic matter, enhance crop yields, improve soil structure and porosity, reduce runoff, enhance the capacity for water retention and often decrease soil temperatures.

Living Mulch. A live mulch is a specialized system of mixed cropping. A low-growing crop, usually a legume, is planted as a cover crop to cover the entire soil surface and control weeds. A small strip is opened to seed the desired crop. Living mulches or fallow crops should not be competitive for light, moisture or nutrients. The advantage of a living mulch is a continuous ground cover that maintains a favorable soil structure. Although the live mulch system may be dependent on availability of herbicides, it has potential for continuous crop production for soils in both tropical and temperate environments.

Plastic Mulches. While the use of plastics in agriculture may be commonly associated only with agriculturally developed countries and advanced technologies involving high capital and resource and management inputs, plastic soil covers are finding a place in both temperate and tropical zone agriculture and in humid as well as arid climates. The expansive use of plastic mulches for cotton, peanuts, watermelons and corn in China enables crop expansion into otherwise inhospitable climates, controls weeds, reduces soil erosion, conserves moisture, extends the cropping season, modifies soil temperature and may even repel insects (24). Plastic soil mulches show promise for enhancing the productivity of cassava, sweet potato and yam production in many tropical countries. They may duplicate, in part, the favorable effects of mulch farming.

The Tillage Revolution

Associated with various traditional soil-mulching techniques in developing countries, zero or reduced tillage has the objective of reducing mechanical manipulation of the soil. It is an integral part of traditional farming in the tropics. There is a minimum disturbance of the soil and vegetative cover under shifting cultivation which minimizes erosion and irreversible degradation of soil quality.

The ultimate challenge for land-use in developing countries is to replace or improve the slash-and-burn or milpa-farming systems, which allow cropping only one year or less in 10, with adjusted no-tillage systems to enable continuous crop production. Some reduced tillage systems are beginning to meet this challenge. Reduced tillage in various forms is now and has been traditionally practiced by subsistence farmers in the tropics without the use of herbicides (12).

No-Tillage farming is growing crops without mechanical manipulation of the soil. Soils that favor this system have coarse-textured surfaces, high porosity, are not susceptible to cracking or crusting, are well-drained and

have an adequate quantity of surface mulch and high biological activity. The use of herbicides is often an essential part of the system. No tillage does not mean just the elimination of tillage. It is only one component of a system that requires mulch management, seeding equipment, weed control, plant protection, crop rotations and crop establishment. Systems have been developed for rice, corn, wheat and many other crops.

Ridge Cropping is often an integral part of land use in developing countries. It is well-adapted for small low-input subsistence farms. Ridging with cross-ties or tied-ridging is an improvement. The system is designed to hold surplus water, allow its infiltration and reduce runoff. It is an effective method of improving water infiltration on structurally inert soil.

Conservation Tillage includes no-till, ridge cropping and any reduced tillage system which results in conservation of soil and water and organic matter and energy as well. Conservation tillage also results in well-developed surface aggregations resulting from high earthworm activity. The benefits are higher yields from lower inputs. There are savings in fuel consumption and in the time needed for seedbed preparation. Herbicide requirements for weed control may be high. Mulch cover is an essential ingredient.

Alley Cropping is a type of agroforestry where food crops are grown in alleys formed by hedge rows of trees or shrubs, usually a legume (10). The hedge rows are cut back when food crops are planted and kept pruned to prevent shading and competition. Mulch is provided from the tree prunings, weeds are suppressed, a favorable microclimate is created, nutrients are recycled, biologically fixed nitrogen is provided the companion crop, and runoff is reduced with conservation of both soil and water. The system has proved ecologically stable and sustainable in the tropics for up to 10 to 12 years.

Allelopathy is a phenomenon whereby one plant or its residues suppresses the growth of other plants. Many plants native to the tropics, where weed problems are often the most severe, have these properties (16). They are often observed in deserts where it is a matter of survival of one plant against another with moisture the limiting factor for growth. Allelopathic properties derive from the presence of natural herbicides. They have also been observed as properties of mulches derived from many commonly grown plants, such as rye, grain sorghum and with annatto grown in the Belize tropics. Allelopathic tillage systems utilizing plants with residues having allelopathic properties are a natural means of reducing or eliminating the costly and sometimes hazardous use of chemical herbicides for weed control.

Irrigation

Irrigation is a major determinant of the use and sustainability of agricultural land and its productivity. Insufficient water is the most important single factor controlling soil productivity. An estimated three-fourths of the potentially arable land in the tropics have limited productivity because of insufficient moisture. Irrigation is the one option

developing nations have for increasing agricultural output from existing land resources and assuring dependability of production.

Water is currently the limiting resource input for agricultural production in each of the five most populous countries on earth--China, India, the Soviet Union, the United States and Indonesia--three of which are developing countries. Supplemental irrigation for overcoming increasingly erratic water supplies in semiarid Africa would reduce the vulnerability to adverse rainfall conditions. Irrigation potentials, however, are not developed in tropical Africa. Only 12 million of the some 270 million hectares of irrigated land on earth are found in Africa, and only two percent of the irrigable land is irrigated of which Egypt and the Sudan account for more than half.

The contrast is in China where 50 percent of the cultivated land is irrigated. The use of dry farming techniques, some of which are almost forgotten, and the expansion of irrigable cropped area deserve high priority in future land development strategies. Low-cost and simple techniques of water harvesting and conservation deserve greater emphasis for land use in developing countries. The Chinese systems should be of interest.

The Chinese Experience

The account of how China, through its blending of traditional with modern technologies ("walking on two legs"), is feeding over 22 percent of the world's population on seven percent of the arable land is a classic of agricultural development and progress during the past 10 years (24). Much of what the United States and the western world has taken credit for in land use was developed in China. Even today the Chinese lead the world in many water management technologies, haploid culture for new crops, hybrid rice production, polyculture of fish, and soybean genetics.

The past and present achievements of the Chinese in food and agriculture are critical for shaping world land use in the future. Steps are being taken in China to stop plundering-like management of soil resources by massive grass planting and reforestation using genetically improved species. Thirty-three million hectares are yet to be reclaimed. China's 540,000 square kilometers of wind-blown highly erodible soil--the Loess Plateau--is the largest in the world and the most erodible. There are over seven million hectares of saline-alkali-salty soils in China. High salt levels occur in the soil as well as the groundwater. These salty soils are being made productive by clever schemes of both irrigation and drainage, green manuring, forest networks and growing of rice.

The Chinese experience on land use involves afforestation which has progressed beyond that of any other nation, and even beyond the expectations of the Chinese. The land area in China currently with forests amount to 12.7 percent. For several years there has been a national movement for reforestation in which all the people in the country participate. This has resulted in six million hectares of reforestation each year. By 1990 forests should cover 20 percent of the land surface area. The results are having positive impacts on land and water stabilization, on reductions in soil erosion, as protective barriers for crops and livestock against wind,

desert and sand encroachments and on the maximization of both food and tree crop production. The least heralded and most important of all has been a shift to using firewood and logs for fuel instead of crop residues, which residues can now be added back to the soil to build up and maintain the organic matter.

Pockets of Success for Land Use in Developing Countries

Aside from the achievements of land use in China there are other examples of success in mobilizing land resources, many of which are occurring in Africa (1,6,8,23). Kenya's national soil program began in 1974 and by 1984 had extended to the terracing of 365,000 farms, or two out of every five in the nation. In Zimbabwe, black maize farmers doubled yields from 1980 to 1985 and harvested more than three times that of 1978. Today in Zimbabwe the maize depots are overflowing with a surplus of a million tons for export. A low-input plant breeding program for root and tuber crops at the International Institute of Tropical Agriculture in Nigeria has resulted in early and super varieties of cassava, yams and sweet potatoes not dependent on fertilizers, pesticides or fungicides. The spread of new varieties has been spontaneous with farmers passing planting material from one neighbor to another.

A water conservation project in the Yatenga Plateau of Burkina Faso is focused on a traditional local technique of placing lines of stones across slopes to slow down runoff. If the stones are exactly aligned with contours, they dam water uphill and give it time to infiltrate. The stone lines take up only one to two percent of the crop land but boost yields by 50 percent.

Other examples of success in land use are the rehabilitation of degraded natural forest and wind breaks in Nigeria, alley cropping in Nigeria, and the easing of fuelwood shortages with improved charcoal stoves in Kenya (7). Scientists in agriculturally developing countries place high priority on developing crop varieties requiring minimal resource inputs, on the management of fragile tropical soils for crop production and on agroforestry (5).

Summary

Land as a natural resource is key to life-supporting systems on a global scale and to food production. Universal problems and changes associated with land use for renewable resource production are soil erosion, deforestation, desertification, excess tillage, salinization, a lack of drainage, aluminum toxicity and the accumulation of heavy metals, and more recently other toxic substances. Neither the magnitudes nor rates of change for many of these phenomena are known. Estimates of changes may differ by several orders of magnitude.

The challenge and issue for land use in developing countries are to improve productivity and land-use intensity of traditional farming (bush fallow, mixed cropping, shifting cultivation, slash and burn, milpa farming) by appropriate inputs of modern technology. Approaches toward this goal are

mulch farming, living mulches, plastic mulches, no-tillage and alley cropping--all utilizing the potentials of allelopathy. The Chinese experience of "walking on two legs," through blending of traditional and modern technologies with social, economic, political, and biological inputs in soil and water management, is worthy of attention by other developing countries. Pockets of successful land and water use in developing countries with low inputs include Kenya's national soil program, maize production in Zimbabwe, the low-input varieties of root and tuber crops and cowpeas developed at the International Institute of Tropical Agriculture in Nigeria, the water conservation project in the Yatenga Plateau of Burkina Faso, hybrid-rice production in China, and hybrid cotton in India.

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THE STATE OF TECHNOLOGICAL SOLUTIONS AVAILABLE FOR EFFECTIVE MANAGEMENT OF SOIL AND WATER RESOURCES

Leo M. Walsh*

Introduction

In general, papers being presented at this seminar will address the critical role of the effective management of soil and water resources in sustaining land productivity. The specific purpose of my presentation is to review technologies available for improved management of these resources.

Any discussion on the status of these technologies must give recognition to the dynamic nature of the problem and the accelerating pace with which change is taking place. We are all familiar with the rapid rate at which population rates are increasing in many areas of the world and the pressure this places on finite soil and water resources. It is also clear that changing perceptions of what constitutes basic individual or community needs places an ever increasing demand on the land resource base.

Though some countries are making significant advances in meeting needs for food production, other areas still lag behind. This disparity is graphically shown in Figure 1. Even in those areas where progress has been made, there is reason to be concerned about this ability of the land resources to sustain the continually expanding need.

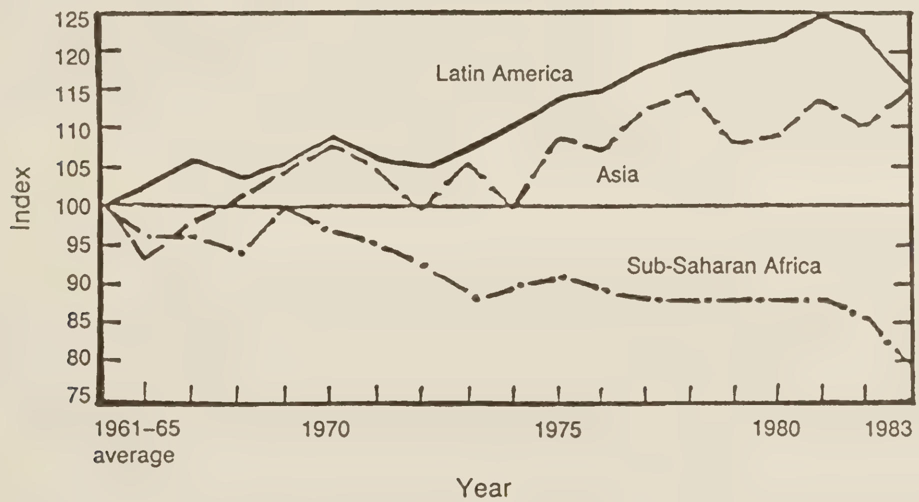

Figure 1. Index of Per Capita Food Production 1961-65 to 1983 (1961-65 Average = 100) (U.S. Department of Agriculture, *In* World Bank, Toward Sustained Development in Sub-Saharan Africa 1984).

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The rapid development of science plays an increasingly important role in the effective long-term use of soil and water resources. The application of science to land-use practices can have very dramatic effects on agricultural systems. Many of these effects are positive but if the practices are improperly used they can have long-term negative effects as well. These conflicting results have led to a somewhat nostalgic desire to return to simpler times of "traditional" agriculture. The problem is that we are not living in simpler times! In fact, "new technologies" were developed because traditional systems were failing to meet changing needs. We must also recognize that many of today's new technologies will be tomorrow's traditional practices.

Unfortunately, the accelerating pace at which new technologies are being introduced does not allow as much time for on-farm adjustments through years of farmer experimentation as was possible only a few decades ago. This reality is causing researchers, educators, extensionists, and community leaders to reevaluate the approach to the application of new technologies. The complex nature of land-use systems, and the interactive effects brought about by changes in individual practices, demands a broader approach to the development and use of new technologies. Multidisciplinary approaches and a broader involvement of groups who play a role in the development, implementation and evaluation of new technologies are needed. This broadened base for development should also improve researchers' ability to anticipate changes resulting from the application of new technology.

Although there never seems to be enough soil and water management technology to keep pace with rapidly changing needs, we are fortunate to have a growing body of fundamental and applied knowledge to improve substantially the productivity and sustainability of soil and water resources. Since it is impossible to describe the complete range of technology developed for sites over the world, a very brief review of some of the more important land classification, agronomic, soil and water control systems and institutional development technologies will follow.

Rational Land Use

The foundation on which national and/or regional programs for sustainable agriculture must be built is the use of land according to its capability for sustained economic production. This involves the development of programs for land capability classification, expanded use of improved agronomic practices, and mechanical soil and water control systems appropriate to land capability classes and farming systems being practiced.

Land Capability Classification. The purpose of land capability classification is to record relevant information which will lead to a decision as to the best combination of agronomic and conservation measures for the most intensive use of agricultural land without excessive risk of degradation.

The technologies for land capability are well established and are widely used around the world. In general, capability classification systems include the following soil factors: 1) effective depth of soil; 2) soil texture; 3) soil permeability; 4) slope; and 5) previous erosion.

The system must, however, reflect conditions in the area where it is to be used. For example, agriculture on the basalt escarpment in Rio Grande do Sul, Brazil, has been producing approximately 60% of the food for the state for the past 100 years, in spite of the fact that none of the soils in this region would be classified as tillable under the USDA system. The Brazilian system, which does not give as much weight to mechanization as does the USDA system and which considers other local factors, classifies approximately 20% of the area as suitable for agricultural production. This illustrates the importance of site-specific information in developing capability classes for specific areas. Lal (1987) points out the importance of considering agroecological zones and the interaction between the biophysical environment and socioeconomic factors in developing land management systems.

The value of technology for land capability classification should not be overlooked in developing national programs. Even a simple system of classification makes it possible to do more effective land-use planning and to make a broader application of site-specific research. This technology should provide information which would encourage intensive use of the more stable areas of agricultural land. Theoretically at least this enables the community to reduce pressures on the more fragile lands. Land suitable for more intensive use may include fertile alluvial soils which are already under irrigation or which might be irrigated. Also included may be lands which have a high potential for production but are not being used intensively because of low fertility or other problems which may be easily corrected with the use of appropriate technologies. For example, estimates of major soil constraints to crop production in the Amazon Basin (Nicholaides *et al.*, 1985) show that the soil fertility and aluminum toxicity are far more prevalent as limiting factors than are erosion hazards, shallow soils or laterization hazard.

Table 1. Gross Estimates of Major Soil Constraints to Crop Production in the Amazon Basin.*

Soil constraint	**Million ha**	**% of Amazon**
Nitrogen deficiency	437	90
Phosphorus deficiency	438	90
Aluminum toxicity	383	78
Potassium deficiency	378	78
Poor drainage and flooding hazard	116	24
High erosion hazard	39	8
Laterization if subsoil exposed	21	4

* Source: Nicholaides *et al.* (1985).

Land Use for Continuous Cultivation. Too often land clearing is done without giving adequate attention to the method to be used in clearing, the capability of the land being cleared, or to the practices which must be used to sustain its productivity once it is cleared. Once a decision is taken to clear land, the method chosen for clearing is extremely important. A number of researchers, (Nicholaides *et al.*, 1985; Lal, 1987; Suebert *et al.*, 1977) have indicated that methods which minimize soil movement while clearing with a tree pusher and root rake followed by plowing is at the other end of the scale. Data from Lal (1981) shows that once an area is cleared the question becomes one of how to protect the soil and keep it productive.

Table 2. Deforestation Effects on Water Runoff and Soil Erosion for Maize-Cassava and Maize-Cowpea (2-year) Rotation During 1970 and 1980 Cropping Seasons.*

Clearing and tillage method	Runoff (mm)	Soil erosion (ton/ha)
Forest control	1	0.01
Traditional farming (shifting cultivation)	7	0.02
Manual clearing, no tillage	16	0.4
Manual clearning, plowed	80	5
Shear-blade clearing, no tillage	105	4
Tree-pusher root-rake clearing, no tillage	107	16
Tree-pusher root-rake clearing, plowed	331	24

* Lal (1981).

Agronomic Practices

The basic relationships of productivity to favorable soil nutritional, biological and physical properties are well established. However, agronomic technologies appropriate to maintaining these properties in different agroecological regions are continually being developed. Lal has reported on relevant work in Africa (1987) and Nicholaides *et al.* (1985) have described various alternatives for the Amazon basin. A brief discussion follows on the relationship of agronomic practices to nutritional, biological and physical properties of soils.

Nutritional Relationships. Technologies which maintain adequate levels of nutrients and reduce the levels of toxic elements (Al and Mn) in soils are not only basic to improved production but also increase ground cover and crop residue to provide organic matter important to sustained productivity.

Improved fertility also increases the variety of crops which can be grown, including legumes which fix higher levels of nitrogen. Unfortunately, most soils in the humid and subhumid tropics are highly weathered and infertile. As these lands are brought into continuous cultivation, technologies which maintain proper nutrient balance through liming and fertilization must be used.

In the late 60s the University of Wisconsin and the Federal University of Rio Grande do Sul, Southern Brazil, established a program of on-farm demonstrations with small farm families on ultisols and oxisols of the Planalto. These farms had been cleared for approximately 30 years and were acid, infertile and often highly eroded. Many of the soils had high levels of exchangeable aluminum and manganese. The basic concept of the program was to reestablish the productivity of these soils by applying corrective treatment of lime and fertilizer, introducing improved varieties of crops and encouraging conservation practices. The only support provided to the farmers was longer-term (four-year) credit for corrective treatment of lime and fertilizer and for terracing. Excellent responses were obtained from the recommended practices as shown in Table 3 (Beatty *et al*. 1972).

Table 3. Average County Yields, Average Yields of Treated and Untreated Farmers' Fields; and Maximum Reported Yields of Corn, Wheat, and Soybeans, 1968-69, Rio Grande do Sul, Brazil.*

Crop	Avg. yield- participating counties	Participating farmers avg. yield on areas: Untreated	Participating farmers avg. yield on areas: Treated	Maximum reported yield
		------ kg/ha ------		
Corn	1,400	1,500	4,230	9,200
Wheat	800	770	1,700	3,900
Soybeans	1,200	1,140	2,340	4,500

* Beatty *et al*. (1972).

Because of the dramatic response, farmers were quick to adopt a whole range of practices to improve and maintain productivity, Table 4 (Murdock *et al*., 1972).

The program expanded from 13 participating farmers in 1966 to more than 35,000 by 1970. Twenty years later, farmers of the area are still maintaining good agronomic practices and productivity. Similar responses have been demonstrated on these types of soils in many parts of the world. Another example shown in Table 5 is the response of crops to lime and phosphate on newly cleared transmigration sites in Indonesia (Rumawas, 1984).

Table 4. **Indicators of Development of Operacao Tatu in Santa Rosa, Rio Grande do Sul, Brazil.****

Indicator	Year 1967	1968	1969
Farmers participating	91	850	1,207
Soil samples analyzed	2,319	2,252	2,239
Soil recuperated* - hectares	100	3,042	5,315
Lime applied - mT	334	11,371	15,480
Fertilizer applied - mT	19	1,220	2,551
Terraces constructed - km	134	1,110	4,211
Hybrid seed corn planted - kg	645	19,819	25,366
Certified wheat planted - kg	0	52,321	258,491

* Limed and fertilized according to recommendations based on soil analyses.
** Murdock *et al.* (1972).

Table 5. **Response of Upland Rice to Lime and Phosphate Application in the 3rd Year, 6th Cropping Season at Sitiung II, Indonesia.***

Limestone	TSP (Kg P_2O_5/ha) 0	50	100	150	200	Average
t/ha	kg/ha					
0	439	3328	3476	4595	4029	3167
1	1850	3589	4304	3914	4517	3635
2	2333	4796	4799	4579	4558	4213
4	3654	4745	4934	4547	4902	4557
8	3954	5395	5449	5036	5357	5038
Average	2447	4363	4592	4534	4675	

* Rumawas (1984)

One of the valuable contributions to research in this area is that of North Carolina State University and the Peruvian Ministry of Agriculture at Yurimaguas, Peru. This research demonstrated that it is possible to sustain improved levels of productivity over long periods with relatively low inputs of fertilizer and lime. This sustained productivity is shown in Figure 2 (Sanchez *et al.*, 1983). During this period, soil nutritional properties improved and organic matter decreased only slightly more over 20 consecutive crops (27%) than it did on the slash-burn control during the first year (25%) (Nicholaides *et al.*, 1985). It should be pointed out that the intensive system provided fresh organic residue with each crop harvest.

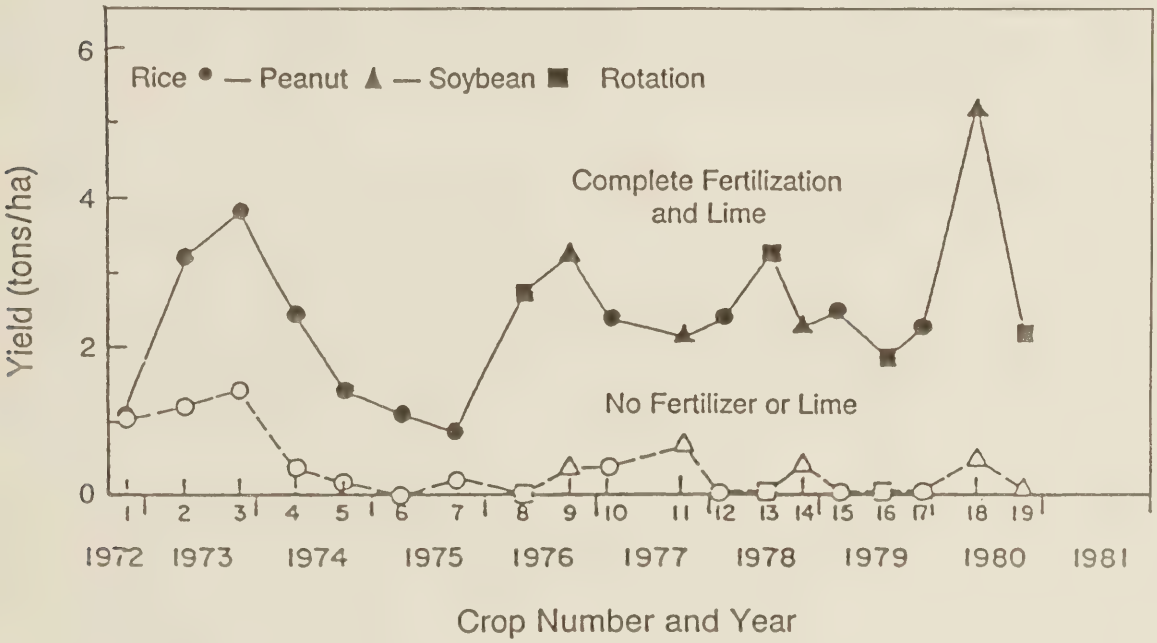

Figure 2. Yield Record for Continuously Cultivated Plots at Yurimaguas, With and Without Fertilization and Lime (Sanchez *et al.*, 1983).

Lal (1987) suggests the use of mulch as a means of enhancing nutritional properties but indicates that use of commercial fertilizers are important for the highly weathered oxisols and ultisols in Africa.

The severity of nutrient deficiencies in soils in the semiarid tropics is not as great as that in the more severely leached soils, but even here crop production is often limited by nutrient deficiencies, especially of nitrogen and phosphorus.

The severity of nutrient deficiencies and toxicities in tropical soils and the difficulty in providing commercial fertilizers for low resource farmers highlight the need to make maximum use of on-farm resources. A wide range of practices are available to accomplish this. Crop rotations/ sequences should include legumes to provide nitrogen as well as crops which will provide residues. Other systems, such as alley cropping, may be used

to provide organic mulch and nutrient cycling. When livestock are a part of the system, crop residue may be used as an important source of the feed, and manure can be used to partially offset fertilizer needs. However, when products move off a field, nutrients go with them and it is impossible to maintain a closed system. Though it would be desirable to eliminate the need to purchase fertilizers, it simply cannot be done--there is no free lunch!

Practices to Improve Biological and Physical Properties. The technologies suggested by Lal (1987) for improving biological and physical properties of soils in Africa focus on soil management technologies designed to give consideration to biophysical and socioeconomic factors. Factors listed as being important to maintaining favorable soil conditions are: 1) undisturbed soil surface; 2) continuous supply of organic matter to the soil as mulch; 3) favorable soil temperature and moisture regimes; 4) high biotic activity of soil fauna; and 5) minimum losses by runoff, erosion or deep leaching.

The basic practices suggested to maintain these conditions in humid and subhumid areas of Africa are those which provide mulch cover and conservation tillage. Mulch may be provided from residue of a previous crop or crop sequence, a cover crop grown every three to four years and/or alley cropping with pruning from hedgerows of *Leucaena* planted two meters apart. No-till farming allows the farmer to put crops through mulch covers without plowing, thus retaining the advantage of the mulch cover and reducing possible compaction and moisture loss through cultivation. Mulching effects on crop yields are shown in Table 6 (Jurion *et al.*, 1969), Table 7 (Lal, 1970) and Table 8 (Lal, 1987).

Table 6. Mulch and Cotton Yield in Zaire (kg/ha).*

	Unmulched		Mulched	
Year	No Fertilizer	Fertilizer	No Fertilizer	Fertilizer
1947-48	1032	--	1127	--
1953-54	200	400	1117	1434
1955-56	186	797	1464	1977
1956-57	124	706	986	1344

* Jurion & Henry (1969)

Table 7. Mulching Effects on Crop Yield.*

	Yield (tons/ha)	
Crop	No mulch	Mulch
Maize	3.0	3.7
Cowpea	0.6	1.1
Soybean	0.6	0.8
Cassava	16.4	28.3
Yam	10.7	17.9

* Lal (1977).

Table 8. Alley Cropping and Crop Performance.*

	Grain yield (tons/ha)	
Treatment	Maize	Cowpea
Plowed	4.2	0.5
No-till	4.3	1.1
Leucaena - 4m	3.9	0.6
Leucaena - 2m	4.0	0.4
Gliricidia - 4m	4.0	0.7
Gliricidia - 2m	3.8	0.6

* Lal (1987).

In spite of the beneficial effects of conservation tillage on most soils, weakly structured soils in semiarid regions have a low level of biological activity and often form surface crusts. Studies presented in Table 9 on these soils which were conducted by IRAT (Charreau, 1977) indicate benefits from mechanical tillage.

Table 9. Percent Increase in Yield by Plowing in Semiarid West Africa.*

Crop	Residue removed	Residue incorporated
Pear millet	21	28
Sorghum	29	26
Maize	27	66
Upland rice	157	46
Cotton (seed)	27	34
Groundnut (pods)	19	7

* Charreau (1977).

Another practice which has been used in semiarid regions to increase the infiltration of water and crop production is tied ridging. Tied-ridge systems involve planting on a contour ridge and then tying the ridges together with small hand-built ridges perpendicular to the contour ridge. This system creates many small reservoirs which trap water allowing it to infiltrate. The effects of tied-ridge systems on crop yields in Tanzania (Dagg *et al.*, 1968) and Burkina Faso (Rodriguez, 1986) are presented in Tables 10 and 11.

Table 10. Tied Ridges and Maize Yield in Tanzania (kg/ha).*

Soil	Flat	Simple ridges	Tied ridges
Black cotton soil	3085(100)	105	106
Lateritic soil	2628(100)	115	131

* Dagg and Macartney (1968).

Table 11. Maize Grain Yield in Tied-Ridge System in Burkina Faso (kg/ha).*

Ridge system	Low fertilizer	High fertilizer
1. Flat	1040	1480
2. Simple ridges	990	1470
3. Alternate ridges tied	1840	2540
4. All ridges tied	2040	3250

* Rodriguez (1986).

It is not practical to attempt to define a specific technology which fits every farming situation, even within a specific agroecological zone and/or land capability class, but basic practices which achieve the five favorable soil conditions listed earlier are available for adaptation to local conditions.

The practices reviewed are intended to protect the soil surface from the puddling and erosive effects of raindrop impact; lower soil surface temperatures; provide nutrition for the crop and for soil-borne organisms; reduce evaporation from the soil surface; and improve surface aggregation and infiltration of water into soil.

Soil and Water Control Measures

A combination of crop management and engineering practices is essential for the control of erosion and the conservation of water on sloping soils. The cost and complexity of engineering structures make the use of crop management practices much more attractive, provided they can effectively control soil and water loss. However, when the limits of crop management practices are reached they must be combined with mechanical soil and water control structures to insure sustained use of these areas for agriculture.

Crop Management Practices. The basic principles outlined above for agronomic practices for continuous cropping slopes also apply here. The effects of mulch (Lal, 1976), alley cropping (Lal, 1987) and no-till (Lal, 1976) systems on runoff and soil erosion are shown in Tables 12, 13, and 14.

Table 12. Soil and Water Conservation with Residue Mulching.*

	Runoff (mm)		Erosion (tons/ha)	
Slope %	No mulch	Mulch	No mulch	Mulch
1	412	0	9	0
5	483	11	134	0.2
10	303	21	137	0.2
15	375	20	96	0.7

* Lal (1976).

Table 13. Alley Cropping and Soil Conservation.*

Treatment	Runoff (mm)	Erosion (tons/ha)
Plowed	232	15
No-till	6	0.03
Leucaena - 4m	10	0.2
Leucaena - 2m	13	0.1
Gliricidia - 4m	20	1.7
Gliricidia - 2m	38	3.3

* Lal (1987).

Table 14. No-Till and Soil Conservation.*

	Runoff (mm)		Erosion (tons/ha)	
Slope %	No mulch	Mulch	No mulch	Mulch
1	11	55	0	1
5	12	159	0.2	8
10	20	52	0.1	4
15	21	90	0.1	24

* Lal (1976).

It is equally important to maintain nutrition, ground cover, and a continuing supply of organic matter on steeper slopes. However, it is sometimes more difficult to fertilize these areas and to maintain adequate mulch cover at critical times. Thus, greater dependence has to be placed on the use of acid-tolerant species and less intensive sequences with perennial crops to maintain soil cover. This might include grass-legume pastures, tree crops or a combination of these in an agroforestry program.

Engineering Practices. During the past 50 years researchers have developed a large body of knowledge relative to soil and water management. Fundamental principles have been established for the mechanics of erosion, the physics and erosivity of rainfall and the erodibility of soils! Predictive models for soil loss, such as the Universal Soil Loss Equation (USLE), or modifications, enable conservationists to predict soil loss under a specific set of conditions. This information has made it possible for engineers to design systems with physical structures that control water movement and reduce erosion. The basic technology involved in the use of these structures is to control water movement on agricultural land. An outline of some of the more common systems follows:

Diversion terraces, graded terraces and waterways are often combined in a system which diverts water flowing from higher ground and intercepts surface runoff and conducts it at nonerosive velocities to a waterway where it can safely be discharged. The technology is well known and widely used in areas of mechanized farming, though not limited in usefulness to these areas. During recent years the design of these systems has been modified to function effectively in combination with conservation tillage and other soil conserving practices.

Bench terracing is a process by which steep slopes are converted into a series of steps with vertical risers separating horizontal or nearly horizontal leges, providing a cultivated step. In many instances the step will have a raised lip on the outer edge to retain irrigation water. Since

the structures are located on steep slopes, mechanization in construction or cultivation is generally impossible. The construction and maintenance of these terraces represents a monumental effort by many people. In places with high population pressures, such as the island of Java where the population in some mountainous areas is approaching 1000 persons km sq^{-1}, the labor force is adequate and the need for land is critical enough to justify this effort.

Contour terraces, level terraces, contour planting and tied-ridge systems are used in various ways. Terraces or ridges constructed on the contour are frequently used in areas of lower rainfall to trap water and hold it until it infiltrates. As with other systems of mechanical control of water, there are many variations on its use. In southern Brazil, where rainfall levels exceed 2000 mm, a system of large contour terraces curved upward at each end is used to trap water causing it to infiltrate. Conservation tillage is used to reduce the amount of water flowing to the terrace. In The Gambia, West Africa, a system is used in which a large contour terrace is placed at the mouth of small depressions that drain into the Gambia River. This terrace prevents the encroachment of salt water which moves upriver during the dry season. During the wet season, the terrace and a system of contour ridges and contour planting slows the movement of water down the slope, reducing erosion and increasing infiltration. As noted in Table 15, tied ridges have also been shown to reduce runoff and erosion in Tanzania (Rounce from Lal, 1987a).

Table 15. Tied Ridges and Erosion Control in Tanzania.*

Treatment	Runoff %	Erosion (tons/ha)
1. No cultivation	48	119
2. Flat cultivation	27	121
3. Tied ridges on contour	0	0
4. Ridges downhill	17	61

* Rounce from Lal (1987a).

Irrigation and Drainage Systems. As is the case with conservation practices, the basic principles of irrigation and drainage are well understood. Also many irrigation and drainage systems have been developed and tested around the world. Yet there are vast acreages of land suitable for irrigation which are not irrigated. The question is not so much one of whether the technology is available but how to adapt the systems to meet local conditions and to evaluate the possible effects of poor design and management of these systems on both on-site and off-site resources. Disruption of fresh water flows by upstream diversion of water, combined

with drought, can reduce stream flows, affecting coastal estuaries and allowing salt water to move upstream. This salt intrusion may in turn reduce water quality for irrigation. The major factors limiting the effective application of known technology appear to be: lack of good local data for problem diagnosis, a too-narrow approach to problem solving and program development, and lack of definition of the respective roles of national institutions.

Organizational Technologies

The importance of accumulated experience and knowledge in the area of organization is often overlooked in discussions of agricultural technology. The most difficult obstacle to overcome in the application of agricultural technology is the development of national organizations (institutions) that provide agricultural services. Effective use of organizational technologies is essential to the fulfillment of the promise of the technologies developed to use soil and water resources effectively in a system of sustainable agriculture.

Institution Building. Researchers involved in institution-building studies recognize that it is impossible to build a single blueprint for institution building. However, a number of useful principles have been developed. Esman *et al.* (1966) suggest that the following components are essential to institutional development.

1. Leadership: Administrative and scientific leadership must be prepared to develop and execute national programs.

2. Philosophy: The organization must establish a deep sense of mission, its reason for being, projected to and accepted as being credible by the groups it serves.

3. Structure: A functional system must be developed that facilitates the communication of policy, decisions, and instructions from higher to lower echelons; provides feedback of requirements, problems and suggestions; and obtains, organizes, allocates and channels resources to points of need.

4. Resources: The organization must have the ability to identify and obtain resources essential for its operations and must distribute these resources to areas of highest priority.

5. Programs: The success or failure of an institution depends on its ability to develop programs which produce outputs the institution professes to provide.

6. Linkages: Those important internal or external relationships essential to the effective operation of an institution must be developed and maintained.

Experience bears out the importance of developing each of these components to build viable institutions. In a review of 30 years of institution-building efforts at the Institut Pertanian Bogor, Murdock *et al.*

(1986) show how the development of mission, training of staff, resource acquisition, program development and linkages have resulted in a dramatic increase in the institutions outputs. In Figure 3, the 1960-1970 period represents a time of intensive preparation of leadership and the introduction of new concepts of higher agricultural education--the period of 1970-75, a time of structural reorganization and program development; and 1975-85, a time of consolidation of effort and rapid increase in output.

Figure 3. Numbers of IPB Students Graduating Each Year (1952-85).

Although this brief outline touches only the surface of this important subject, the intent is to emphasize the need to develop effective national institutions for agricultural services that can develop and implement effective soil and water management programs. Technologies to accomplish this are available.

Community Involvement and Systems Approaches. The importance of involving a broad base of community action in the development and implementation of new programs has been demonstrated time and again; there continues to be a need for expansion of this concept in actual practice. This is especially true in soil and water management programs where the effects of practices do not stop at the farm boundary. No major program of soil and water conservation can succeed without a broad base of cooperation. Good examples of this type of organization are the soil and water conservation districts in the United States. These organizations are community-based with strong support from county, state and national agencies.

Technologies for sustaining effective soil and water management practices cover a broad range of disciplines, require a much broader base of knowledge, and are much more site-specific than production "packages" of the past. New approaches to the application of technology to resolve today's problems are needed. Soil and water management technologies require a different organizational approach and strong national agencies to support them. It is one thing to introduce a new variety and quite another to introduce a new soil and water management system. In his discussion of organizational changes for extension, Patton (1987) makes an interesting comparison of industrial-age to information-age organizations as shown in Table 16.

Table 16. Comparative Characteristics of the Industrial-Age and Information-Age Extension Organizations.*

Industrial-age organization	Information-age organization
1. Focus on measurable outcomes.	1. Focus on strategic issues.
2. Highly specialized knowledge base.	2. Interdisciplinary knowledge base.
3. Individual accountability.	3. Team accountability.
4. Clearly differentiated and segmented organizational positions, roles, and responsibilities.	4. Matrix organizational arrangements--flexible positions, roles, and responsibilities.
5. Linear input-output thinking about programs.	5. Holistic systems perspective on programming.
6. Reactive in solving problems as they emerge.	6. Proactive in anticipating issues before they become crises.
7. Local county perspective informs programming.	7. Global perspective informs local action.
8. Hierarchical, linear information flows.	8. Multiple interface information networking.
9. Attention to quantitative differences.	9. Attention to qualitative differences.
10. Staff training.	10. Staff development.
11. Achieving effectiveness through methods.	11. Achieving excellence undergirded by values.
12. Present-oriented, doing what is known now.	12. Future-oriented, operating on the cutting edge.

* Patton (1987).

This comparison reflects some of the thinking behind efforts to develop farming systems research extension and other integrated systems approaches to agricultural development.

Tools for Soil and Water Management

Perhaps the most difficult tasks in developing appropriate, site-specific technologies for soil-and-water management are those that facilitate the survey of resources, the collection of data about the environment, and the development of systems to organize information in ways that help the conservationist to predict the effect of changes in practices on such things as soil and water loss.

The advent of the personal computer and the accompanying technology has greatly amplified the potential for developing more effective information management systems. The low power requirements of solid state electronics make it possible for the researcher to set up battery or even solar-powered systems for making environmental measurements and for logging them even at isolated locations. The computer facilitates the processing of data and the development of complex models which in turn facilitate the study of environmental, hydrologic, soil and agricultural production systems. For example, Swan *et al.* (1987), used this technology to develop a model which predicts the effects of soil depth under various tillage systems on crop yield, Figure 4. There are many other much more complex models in use.

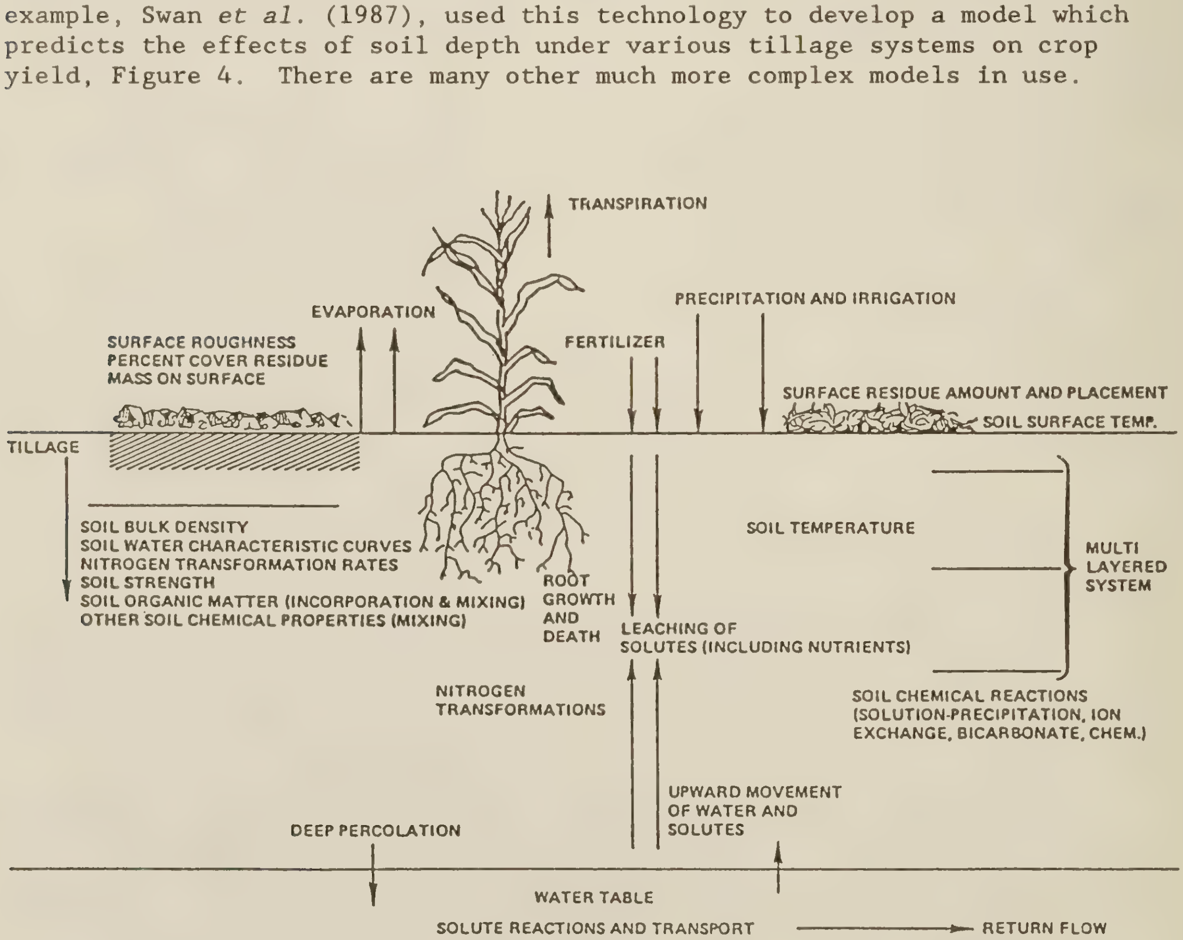

Figure 4. Processes Simulated by the NTRM Model to Related Yields to Soil Depth to Residuum (Swan *et al.*, 1987).

The use of personal computers for digital image processing of remotely sensed data has moved this technology out of highly specialized, expensive laboratories to local laboratories which can make most effective use of the technology for developing geographic information systems, resource survey and environment monitoring. The usefulness of these systems is increasing as the level of resolution from satellite-borne sensors has increased. The diagram of a microcomputer-based Digital Image Processing Laboratory developed by the IES-ERSC at the University of Wisconsin for the Institut Pertanian Bogor is shown in Figure 5 (Ahearn, 1985).

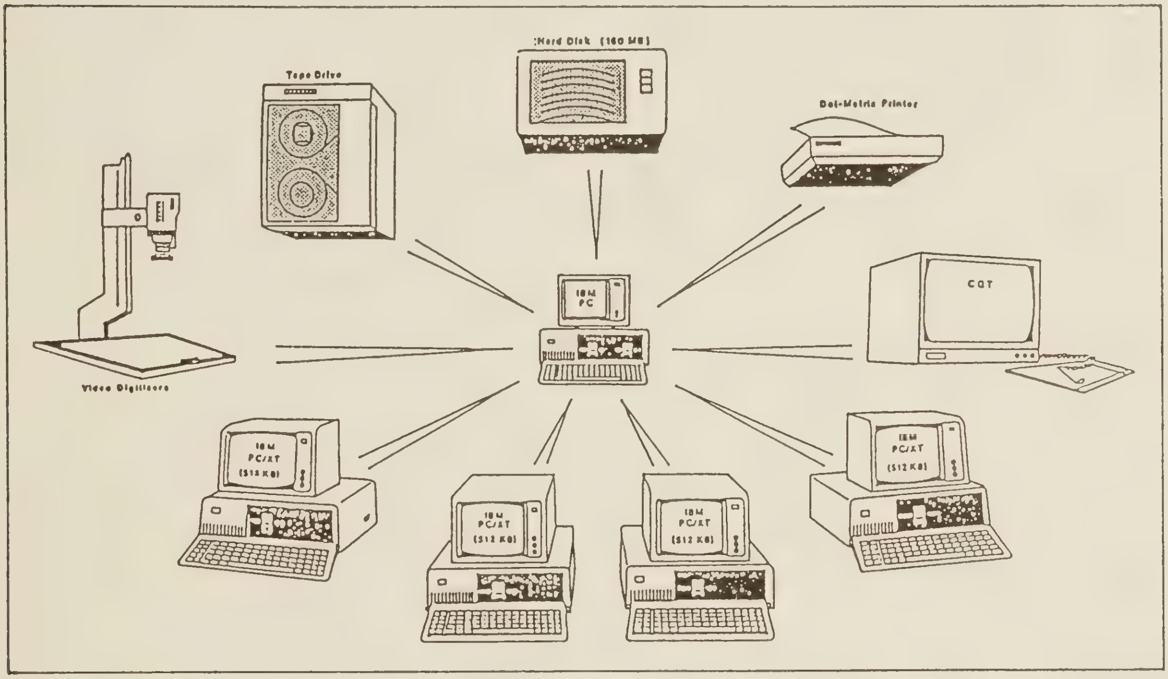

Figure 5. IPB-UW Image Processing System Hardware (Ahearn, 1985).

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RAPID APPRAISAL TECHNIQUES FOR SUSTAINABLE DEVELOPMENT

Gordon R. Conway

For a variety of reasons achieving sustainable rural development is not an easy task. It is possible, given appropriate skills and knowledge, to design agricultural technologies that are sustainable in biological and physical terms. But this provides only part of the answer. In addition to being ecologically sustainable, development also has to be sustainable in social and economic terms. If we envisage three circles representing sustainability domains, as in Figure 1, then the goal is to steer development into the relatively narrow pathway where the domains overlap.

In practice this means that effective rural research and extension must draw on the combined skills and insights of a wide range of disciplines spanning the natural and social sciences and involve workers from all relevant sectors. Developing country environments are under pressures from growing rural populations and declining resource availability, and while, in the past, many rural populations, particularly on marginal lands, were isolated from modern industrialized society, this is no longer the case. Expectations are rising and technological innovations are reaching the remotest corners of the globe. Deciding which innovations or interventions are appropriate, in both the long and short term, requires careful analysis and a genuine dialogue between development specialists, policymakers and, neither last nor least, the farmers themselves.

Moreover, the challenge is not solely one of ensuring that the analyses are careful, insightful and multidisciplinary in nature. Poor farmers cannot wait for the results of time-consuming academic studies. The need is for methods that are powerful and quick and, given the current economic climate of development aid, are also expensive.

The following is a brief review of a number of such methods which fall under the general headings of Rapid Rural Appraisal (RRA) and Agroecosystem Analysis (AEA).

Multidisciplinary Analysis

Work on the development of Agroecosystem Analysis began at the University of Chiang Mai in northern Thailand about 10 years ago. The University had long been a recipient of development aid from the Ford Foundation.

In 1986, a grant had been given to create a Multiple Cropping Project (MCP), aimed at designing advanced triple-crop, rotational systems that farmers could use to capitalize on the government irrigation schemes that had recently been installed in the Chiang Mai Valley. At the same time many of the young staff were given scholarships to go abroad for further graduate training.

In the late 1970s, they returned, eager to put their new skills and experience to the task of helping the farmers of the valley. But, almost immediately, they realized that much of the work of the MCP in the intervening years had not proven particularly relevant. Although the MCP had developed some half-dozen apparently superior and productive crop systems, there were very few cases of adoption by the farmers. On the other hand, the farmers had developed a large number of triple-crop systems in response to the new opportunities that the irrigation had provided.

This realization raised questions in the minds of the staff as to the role they, as university researchers, could most effectively play. In terms of helping the farmers of the valley, where did their comparative advantage lie? Should they continue to design new systems? If not, what kind of research should they undertake? They further realized that these questions could not be answered until they had a better idea of the existing farming systems in the valley and the particular problems that the farmers were currently facing. The team at Chiang Mai, numbering some 20 academic staff, then spent approximately a year developing an approach that would give them the answers (Gypmantasiri *et al.*, 1980).

It was soon realized that the multidisciplinary analysis requires more than simply having a research or development team that works well together and is sensitive to the requirements of good communication. The generation of good interdisciplinary insights also requires organizing concepts and relatively formal, i.e., semistructured, working procedures (Conway, 1985). The concepts have to be fairly simple and involve a minimal set of assumptions that are acceptable to all disciplines. They also have to be understandable, at least in essence, by those with whom the development professionals are working, that is, both policymakers and the farmers.

Agroecosystem Concepts

Three basic concepts were developed that appear to meet these requirements.

The first is that agricultural land use can be represented as a set of more or less distinct agroecosystems, typically arranged in a hierarchic fashion (Figure 2). An agroecosystem can be defined as an ecological system partly modified by humans for the purpose of food or fibre production. The rice field is an example of such a system. Its ecological features are represented by such processes as competition between the rice and the weeds, herbivory of the rice by pests, and predation of pests by their natural enemies. But these processes are overlain by the agricultural processes of cultivation, subsidy, control and harvesting, and by the socioeconomic relationships among the people who work in the field and benefit from its harvest. Essentially the same picture of ecological processes overlain by socioeconomic processes can be drawn for higher systems in the hierarchy, for the farm, village or watershed.

Each agroecosystem also has a characteristic behavior that may be summarized by four interconnected properties (Conway, 1987) (Figure 3):

Productivity, which is the output of valued product per unit of resource input (e.g., land, labor, energy or capital) and is commonly measured as annual yield or net income per hectare or per agroecosystem, or per man-hour or unit of investment.

Stability, which is the constancy of productivity about its long-term trend in the face of small disturbing forces arising from the normal fluctuations and cycles in the surrounding environment; for example, in the climate or in the economic conditions of the market. Such forces affect the variability of production but leave the long-term trend unchanged. Stability is most conveniently measured by the coefficient of variation in productivity.

Sustainability, which can be defined as the ability of an agroecosystem to maintain its productivity when subject to stress or shock. A stress is here defined as a frequent, sometimes continuous, relatively small and predictable disturbing force which has a large cumulative effect; for example, salinity, toxicity, indebtedness or declining market demand. A shock, by contrast, is an irregular, infrequent, relatively large and unpredictable disturbing force, such as a rare drought or flood or a new pest or the sudden rise of an input price. Stresses and shocks have the potential of causing lower or declining trends in production or even collapse.

Equitability, which is a measure of how evenly the productivity of the agroecosystem is distributed among its human beneficiaries. The more equitable the system the more evenly are the products, the food or the income, shared among the population of the farm, village, region or nation. It can be represented by a statistical distribution or by a measure such as the Gini coefficient.

These four properties are essentially descriptive in nature, summarizing the status of the agroecosystem. But they can also be used in a normative fashion, as indicators of performance, both in the design of agricultural innovation and in its subsequent evaluation. Experience shows that in agricultural development there is almost inevitably some degree of trade-off between these different properties. The challenge for Rapid Rural Appraisal is to foresee accurately these trade-offs and ensure they are taken into account in project planning and management.

Agroecosystem Analysis

The next step was then to use these concepts as a basis for analysis, both in the field and in a workshop environment. It was soon found that the most powerful analytical tools were simple, but well-designed, descriptive diagrams. These were prepared in the field from direct observation and through interviews with farmers. They were then used in a workshop to facilitate communication among the different disciplines and to pinpoint the critical problems and opportunities facing farmers; and hence to identify the key research priorities. The priorities were laid out as a set of key research questions with accompanying hypotheses and an outline of the research work that was needed. In the years that followed, the Chiang Mai team has used the list as a guide to its research and has been able to provide an impressive number of answers to the questions.

The method was taken subsequently to Khon Kaen University in the northeast of Thailand, where it was adapted to the problems of analyzing the semiarid agroecosystems of northeast Thailand (KKU-Ford Cropping Systems Project, 1982a, b; Limpinuntana and Patanothai, 1984), and thence to Indonesia where it was applied to the analysis of the research needs of, respectively, the uplands of Java, the tidal swamplands of Kalimantan and the semiarid drylands of Timor (KEPAS, 1985a, b; KEPAS, 1986).

More recently, however, it has been used as a method for determining development priorities for the Aga Khan Rural Support Program in the northern areas of Pakistan (Conway *et al.*, 1986; Conway *et al.*, 1987). Here the need was for an even more rapid method of multidisciplinary diagnosis. Again the emphasis was on the preparation of simple yet powerful diagrams. Maps and transects, for example, were used in describing spatial patterns in the villages and in locating particular problems or opportunities (Figure 4). Seasonal calendars were used to portray changes over time in such factors as climate, crops, livestock, and labor demand (Figure 5). These served to identify the timing of constraints and problems and also the times of year when opportunities for development arise. Production and marketing flows were used to pinpoint the stages when critical problems and threats arise and hence to identify solutions or counters (Figure 6). Finally, the patterns of decision-making were summarized in decision trees or Venn diagrams (Figure 7).

It was found that the field work and the preparation of the diagrams could be produced in a couple of days' visit to each village. The diagrams were then converted to overhead transparencies and used as the focus of a half- to one-day workshop involving the field team and other members of the development group. In this workshop, however, the focus was on producing a set of key development questions and related working hypothesis (Table 1).

Table 1. Examples of key questions relating to the development of the new land in a village in Northern Pakistan.*

Key Question 1:	How can soil development be speeded up while at the same time providing a higher return on new land?
Working Hypothesis:	The third terrace should be planted with apples, peaches, apricots and cherries, plus alfalfa. Second terrace should be planted with willow, rubinia, alfalfa and perennial grasses.
Key Question 2:	How can land be used efficiently after reclamation?
Working Hypothesis:	After 7 years, 25% of the land should be utilized for potato and the rest planted to wheat, barley, and fruit trees. Alfalfa and grasses should be planted on the second terrace.

* Conway *et al.* (1985).

In the final phase of the workshop the innovations and interventions implicit in the key questions were assessed in terms of their effects on the system properties (productivity, stability, sustainability and equitability) and, using other criteria such as cost, assigned priorities for action (Table 2).

A guide to Agroecosystem Analysis is to be found in Conway (1986).

Rapid Rural Appraisal

Agroecosystem Analysis, as described above, is but one of a number of methods of Rapid Rural Appraisal (RRA) developed over the last decade.

RRA may be defined as a systematic, but semistructured, activity carried out in the field by a multidisciplinary team and designed to acquire quickly new information on, and new hypotheses about, rural life (Conway and McCracken, 1988).

Two themes are central to the philosophy of RRA. The first is the pursuit of "optimal ignorance." This implies that both the amount and the detail of information required to formulate useful hypotheses in a limited period of time are regarded as expenses to be kept to a minimum. In terms of the concepts presented earlier, the aim of the multidisciplinary team is to arrive at an agreed sufficiency of knowledge of the key agroecosystem processes and properties relevant to the objectives of the RRA and not to exceed this by investigating irrelevant aspects or being concerned with unnecessary detail.

The second theme is diversity of analysis. This is pursued through the process of "triangulation," that is, the use of several different sources of, and means of gathering, information. Notwithstanding the self-imposed limits of time and resources, the accuracy and completeness of an RRA study is maximized by investigating each aspect of the situation in a variety of ways. "Truth" is approached through the rapid build-up of diverse information rather than via statistical replication. Secondary data, direct observation in the field, semistructured interviews, and the preparation of diagrams all contribute to a progressively accurate analysis of the situation under investigation.

These themes in turn lead to five key features of good RRAs, namely that they are:

<u>Iterative</u>. The process and goals of the study are not immutably fixed beforehand but modified as the team realizes what is or is not relevant.

<u>Innovative</u>. There is no simple, standardized methodology. Techniques are developed for particular situations depending on the skills and knowledge available.

<u>Interactive</u>. All team members and disciplines combine together in a way that fosters serendipity and interdisciplinary insights.

Table 2. Innovation assessment for a village in Northern Pakistan (+ positive, - negative, 0 neutral effects, H high, M medium, S short or small, L long).*

INNOVATION	Productivity	Stability	Sustainability	Equitability	Cost	Time for Benefits	Feasibility	Priority
Development of 2nd terrace	+	+	+	++	H	M	+++	3
Development of 3rd terrace	+++	+	+(?0)	+	H	L	++	1
Artificial insemination	++	+	?	-	M	M	++	2
Catch crops	+	+	+	0	S	S	+	3
River bunds	0	+	+	+	H	S	++	4
Potato intensification	++++	+	-	+	S	S	++	2
Involvement of women	++	+	+	+++	S	M	+	2

* Conway *et al.*, (1985).

Informal. The emphasis is, in contrast to the formality of other approaches, on partly structured and informal interviews and discussions.

In the field. The aim is not just to gather data for later analysis. Learning takes place largely in the field "as you go," or immediately after, in short, intensive workshops.

Studies of local rural situations in developing countries have often concentrated on only one set of conditions, investigating for instance the economic, social, ecological or agricultural aspects. Where several sectors are included, as in project designs, they are often still considered in isolation from each other; at best being collected together in a single voluminous report. Extensive data collections, involving many researchers, over a long period of time and costing large sums of money, are often regarded as integral to the process. These are usually followed by equally extensive statistical analyses, although often remaining narrow in their focus and assumptions.

The obvious logistical problems of such an approach are frequently accompanied by other, more serious, shortcomings. Local inhabitants are seldom consulted, or at best through fixed and formal channels; for instance, by means of a written questionnaire with the questions determined beforehand and unchanged from day to day of the study, or from farm to farm or village to village. The context of the target data is frequently ignored; "averages" are sought, while significant variations are often missed. This gives little opportunity for new features of the system to be revealed or for insights to be gained other than those which could have been learned at the start from the local people.

Such inflexible methodologies are also responsible for the collection of many irrelevant data and the discharged of local peculiarities in, for example, the ecological, economic or cultural conditions. Delay in providing the results can sometimes lead to them being useless in the "by-then-changed" situation. A general consequence is that development projects fail through a combination of incorrect knowledge and a lack of cooperation on the part of "those being developed."

The work of the early practitioners of RRA was brought together in conferences at the Institute of Development Studies, University of Sussex, in October 1978, and December 1979 (Agricultural Administration, 1981). A more recent conference was held in September 1985, at Khon Kaen University, Thailand (Khon Kaen University, 1978). Other key papers include those by Hildebrand, 1981; Rhoades, 1984; Hondale, 1982; and Collinson, 1981.

There is no single, standardized methodology for RRA. In each situation this depends on the objectives, local conditions, skills and resources. However, there is a suite of techniques in existence which can be used in various combinations to produce appropriate RRA methods. The suite includes: secondary data review; direct observation; diagrammatic models; semistructured interviews; and analytical workshops.

Secondary data consists of such items as reports, maps, and aerial photographs that already exist and are relevant to the project. The review process involves searching for relevant data and summarizing these in

diagrammatic models, simple tables and brief abstracts. The aim is to be skeptical and critical and to look out for what has been missed but not to spend time here that could be better spent in the field.

Direct observation includes measurement and recording of objects, events, and processes in the field, either because they are important in their own right or because they are surrogates for other variables that are important.

One of the most important of RRA techniques is semistructured interviewing, a form of guided interviewing where only some of the questions are predetermined and new questions or lines of questioning arise during the conduct of the interview in response to answers from those interviewed. The information is thus derived from the interaction between the knowledge and experience of the interviewer and the interviewee(s). The latter may be groups of village leaders or key informants, such as school teachers or local government officials, or the farmers themselves, selected on one or more criteria.

Diagrammatic models and the analytical workshop have already been described.

The various techniques described above will be used in various combinations depending on the objective of the RRA. Very broadly there are four principal classes of RRA, which ideally follow one another in the sequence of development activity:

Exploratory RRAs to obtain information about a new topic or agroecosystem. The output is usually a set of preliminary key questions and hypotheses. (Agroecosystem Analysis is an example of an exploratory RRA).

Topical RRA to investigate a specific topic, often in the form of a key question and hypothesis generated by the exploratory RRA. The output is usually a detailed and extended hypothesis that can be used as a strong basis for research or development.

Participatory RRA to involve villagers and local officials in decisions about further action based on the hypotheses produced by the exploratory or topical RRAs. The output is farmer-managed trials or a development activity in which the villagers are closely involved.

Monitoring RRA to monitor progress in the trials and experiments and in the implementation of the development activity. The output is usually a revised hypothesis together with consequent changes in the trials or development intervention which will hopefully bring about improved benefits.

There is not space here to describe the form of topical, participatory and monitoring RRAs, but they are described in various references (Khon Kaen University, 1987; Conway and McCracken, 1988; Conway and Sajise, 1986; McCracken, 1988; Chambers, 1988).

RRA in the Project Cycle

A traditional project cycle, particularly as it applies to large investment projects, goes through the sequential phases of data acquisition, analysis, planning, implementation, review and redesign (Figure 7). It is ordered and methodical but is often a costly and time-consuming exercise. The logical progression is one which is designed to ensure that all factors and considerations are incorporated. But, as experience has shown, such an approach tends to become rigid and bureaucratized in practice. Critical questions are not asked and important insights are missed. At the other extreme is a project cycle which simply moves rapidly from identifying problems to solving them and back again (Figure 8). This approach is based on a close relationship between development professionals and farmers and can only really be undertaken on a small and intimate scale.

This latter scheme relies entirely on RRAs. However, RRA has its limitations. It will never, and indeed was never designed to, make redundant more traditional, formal and detailed surveys and analyses. RRAs and RRA techniques essentially complement more formal methods and while in some situations they may be substitutes, more often than not, they are preliminary exercises, leading up to more detailed analyses.

The advent of RRA has thus greatly enriched the availability of methods of analysis for rural development. Techniques can be chosen on the basis of the nature of the problem, the local situation and the resources at hand. In particular, different techniques, both formal and informal, can be blended to produce a project cycle along the lines of Figure 9. This lies some way between the extremes of the schemes in Figures 7 and 8, and can be applied to a wide range of projects, both large and small in conception. In such a scheme the primary role of the RRA is to define and refine hypotheses which are then tested, either formally or informally, as part of the project cycle. Providing the cycle is iterative, flexible and open, it should be possible to combine speed with both rigor and sensitivity, resulting in development that is not only productive but durable and equitable in its benefits.

Rapid Appraisal Techniques in Thailand

Finally, I want to indicate briefly the progress that has been made in Thailand in developing and applying these tools and approaches over the past decade.

Chiang Mai University, where it all began in Thailand, has become a center of excellence in agroecosystem research and training. Its research program is concentrating on the crucial problems of sustainability of the intensive irrigated agriculture of the Chiang Mai Valley. In training it has pioneered a highly innovative M.Sc. degree program in Agricultural Systems, originally offered in Thai, but shortly to be given in English and open to students from all of southeast Asia.

Khon Kaen University has similarly become a center of excellence in sustainability research but focusing, with support from the U.S. Agency for International Development (USAID), on the difficult problems of achieving

lasting, real increases in productivity in semiarid conditions. They have also become world leaders in the techniques of RRA and were recently hosts to a highly successful international conference on the subject (Khon Kaen University, 1987).

In the northeast of Thailand, the USAID-funded Northeast Rainfed Agricultural Development Project (NERAD), based at the Regional Office of Agriculture, has been notably successful in adapting the more research-oriented techniques developed in the universities for use as practical tools in district and village planning and in developing an innovative range of new analytical tools (*e.g.*, Alton and Craig, 1987).

In the past couple of years, these skills and experiences (and similar expertise at the Prince of Songkla University in the south of Thailand) have increasingly come to the notice of the various agencies of the Ministry of Agriculture and Cooperatives, particularly as tools in planning for a greater diversity and intensification of Thailand's agriculture. The universities and NERAD have conducted a large number of training courses for Ministry staff and for members of the Provincial agricultural development committees. USAID is now considering providing substantial support to extend this training and research, under its new proposed Natural Resources Management Project, with the aim of helping Thailand in its quest for sustainable development.

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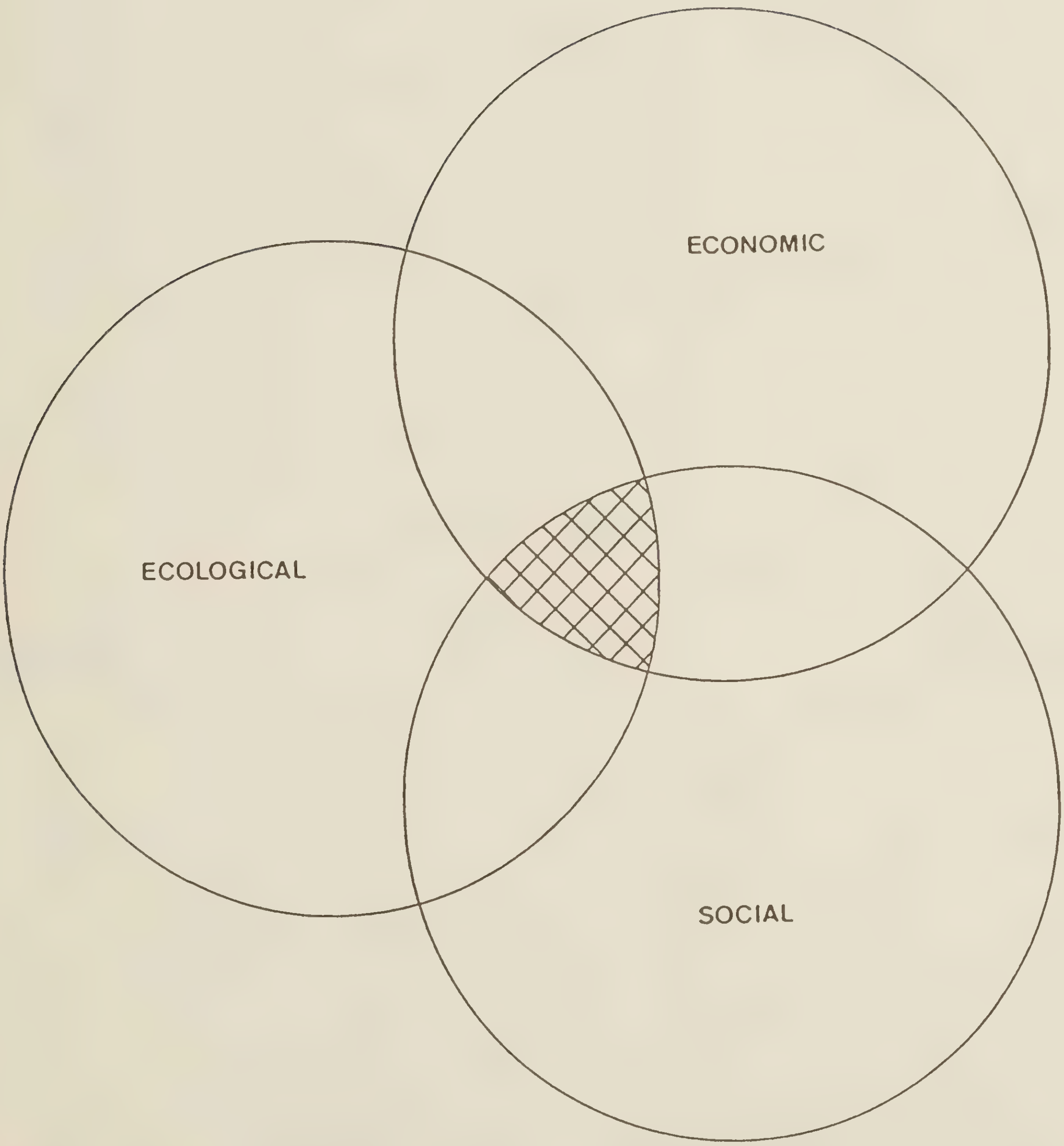


Figure 1. Sustainability domains for agricultural development.

Figure 2. The hierarchy of agroecosystems.

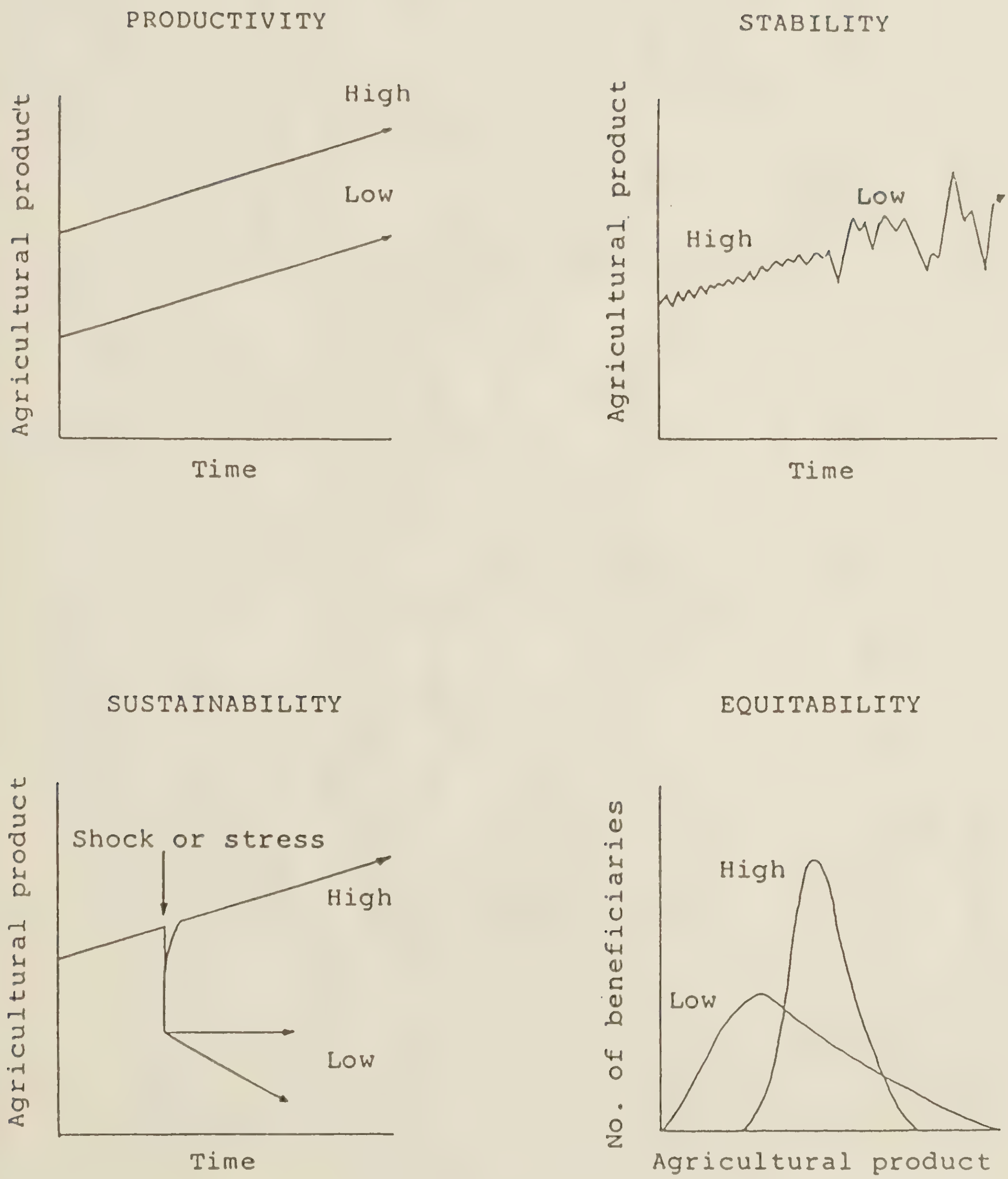
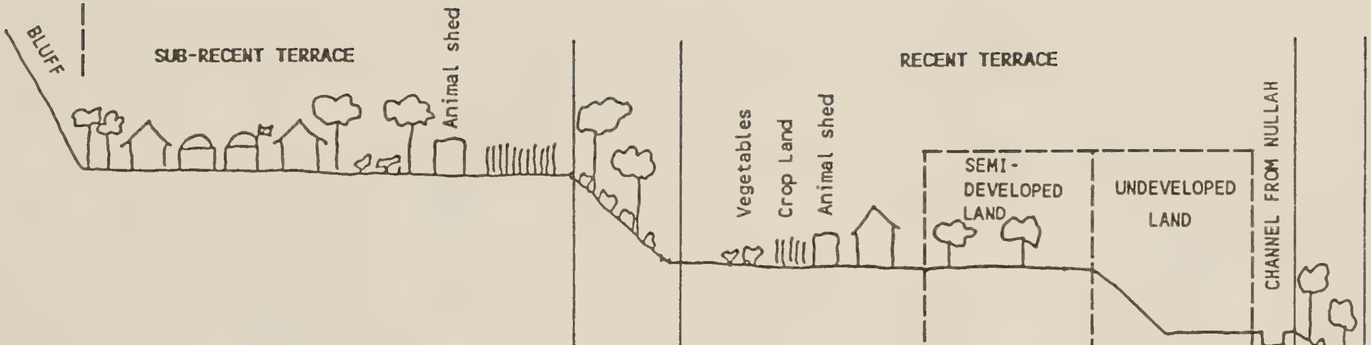


Figure 3. The properties of agroecosystems.



SOIL	Loam	Stony Large Boulders	Sandy Loam	Stony Sand	Stony Sand
CROPS	Wheat - maize, mash Wheat - fallow Vegetables Potatoes	Bushes Trees	As for recent terrace	Willow Poplar Russian olive Thorny bushes	Scattered trees
LIVESTOCK	Ruminants Free grazing in winter	Grazing	Free grazing	Grazing	
PROBLEMS	Pod Borer in mash Water flooding from fan Water shortages	Poor Soil	Serious water shortages	Poor soil	Flooding
OPPORTUNITIES	Pest control Extend canals - irrigation and water control		Improve grazing Extend canals	More trees	Alfalfa irrigation

Figure 4. Transect of a village in Northern Pakistan (Conway *et al.*, 1987).

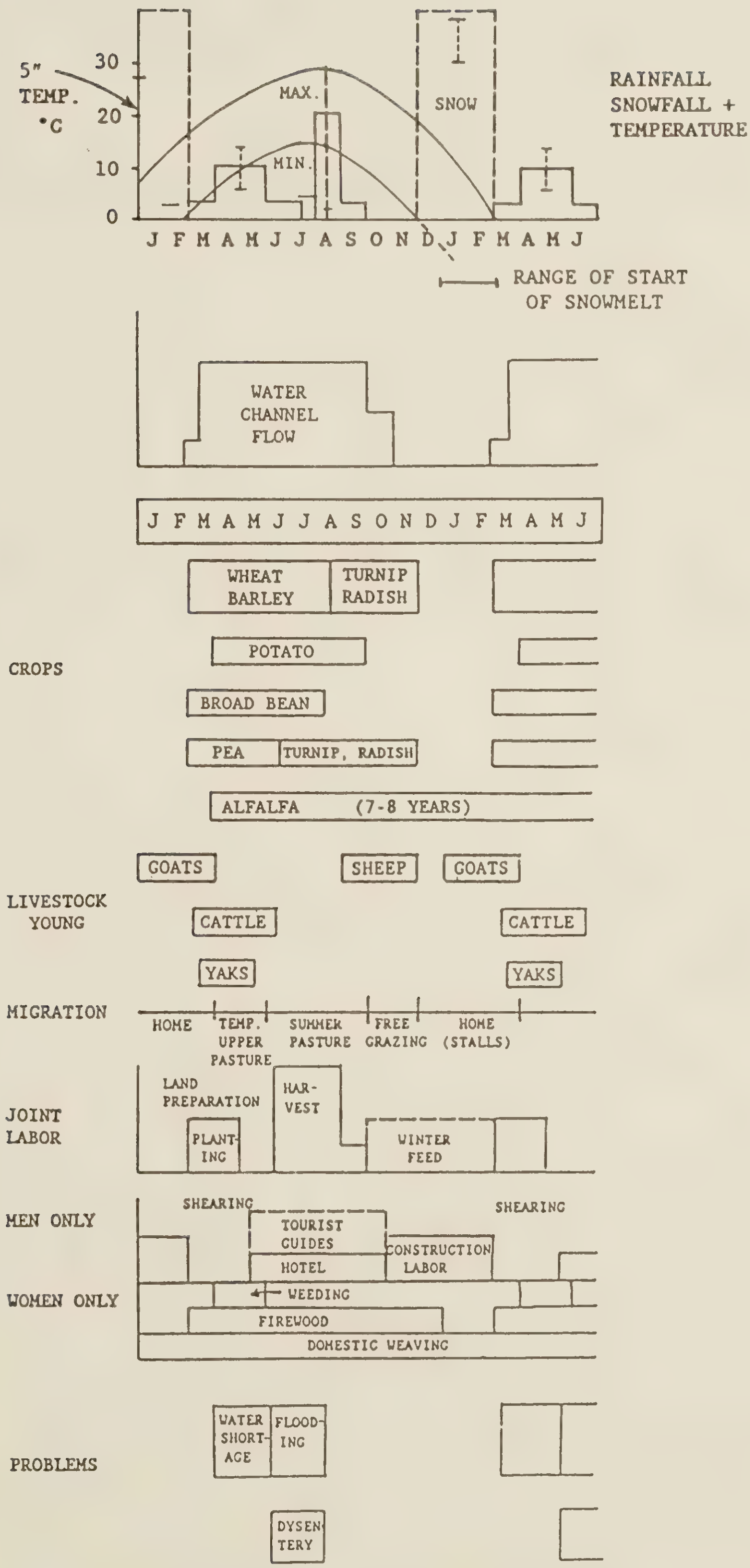


Figure 5. Seasonal calendar for a village in Northern Pakistan (Conway *et al.*, 1987).

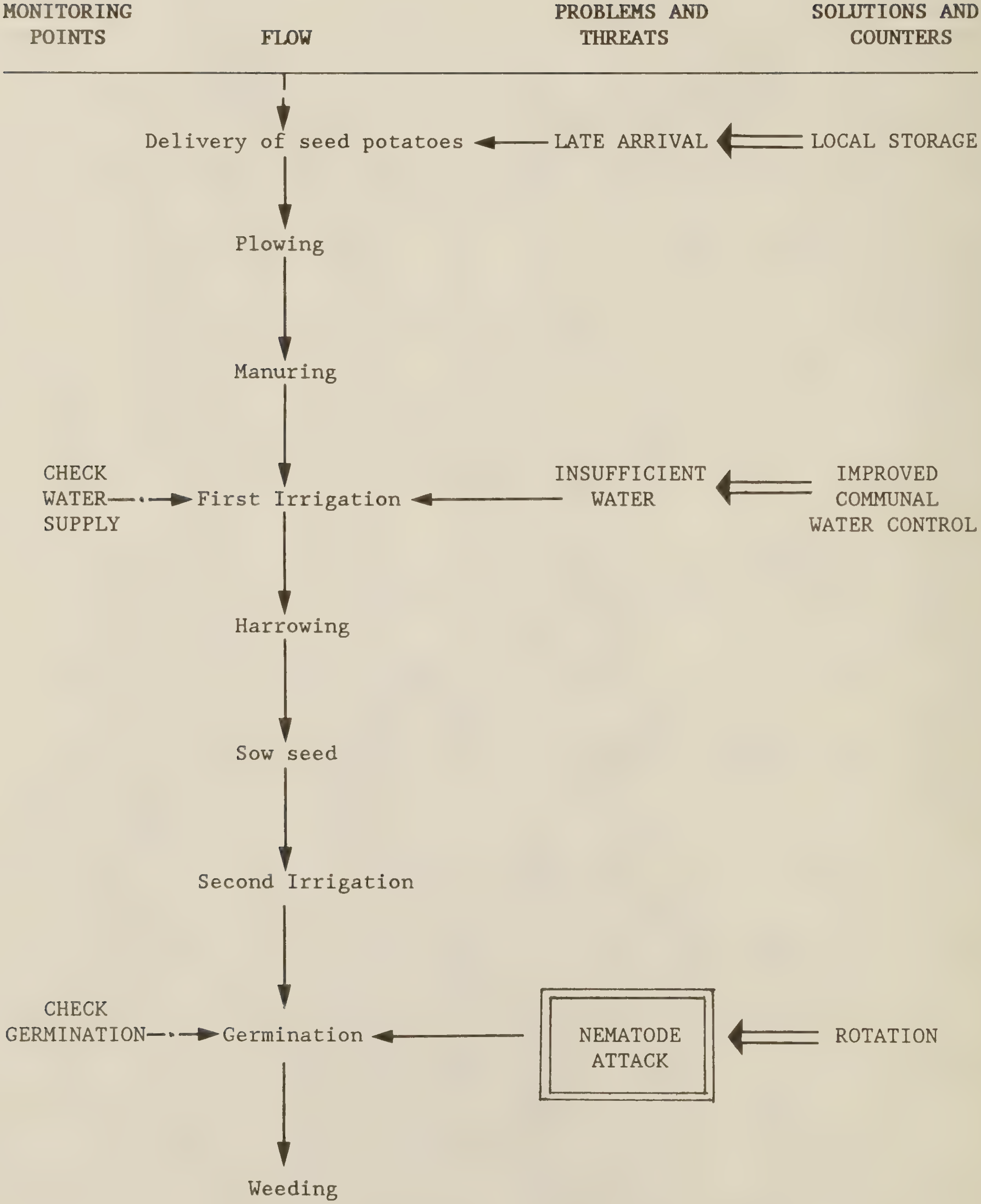


Figure 6. Extract from a sustainability analysis diagram for seed potato production in Northern Pakistan.

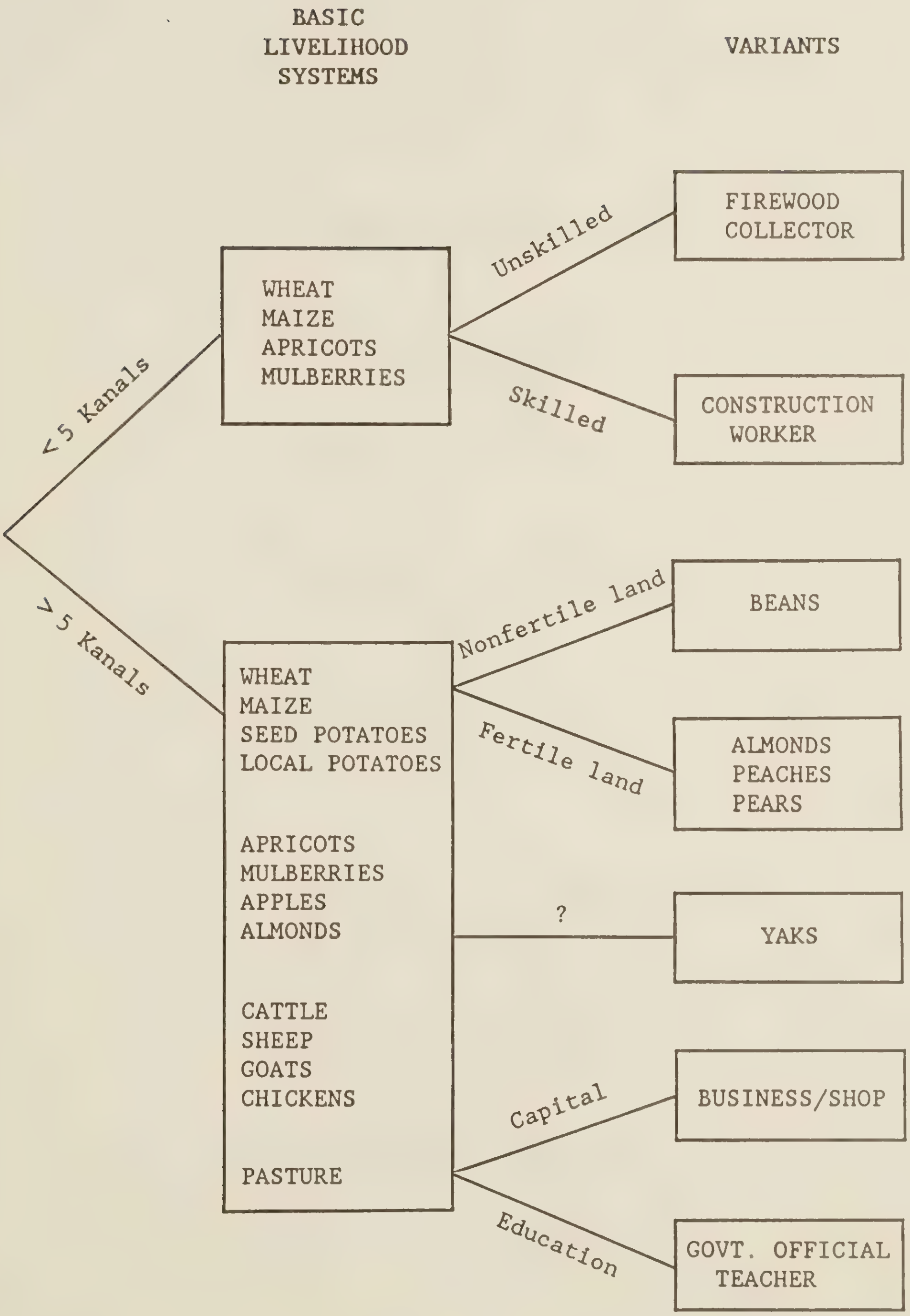


Figure 7. Decision tree for livelihood systems in Northern Pakistan Village (Conway *et al.*, 1987).

	BROAD OBJECTIVE
	DATA ACQUISITION
1-5 yr.	Formal Surveys
6 mos.-1 yr.	ANALYSIS OF DATA
	Statistical Analysis
	COLLATION OF REPORTS
1 yr.	ASSEMBLE PROJECT PLAN
3-5 yr.	IMPLEMENTATION
6 mos.	REVIEW
1-5 yr.	Formal Surveys
6 mos.	PROPOSE MODIFICATIONS
3 yr.	NEXT PHASE IMPLEMENTATION

Figure 8. Formal model for project design and implementation (Conway and McCracken, 1988).

ASK FARMERS WHAT THEIR PROBLEMS ARE

INVESTIGATE PROBLEM

Topical RRA

SOLVE PROBLEMS WITH FARMERS

Participatory RRA

DISCUSS SOLUTIONS WITH FARMERS

Figure 8b. Informal model for project design and implementation (Conway and McCracken, 1988)

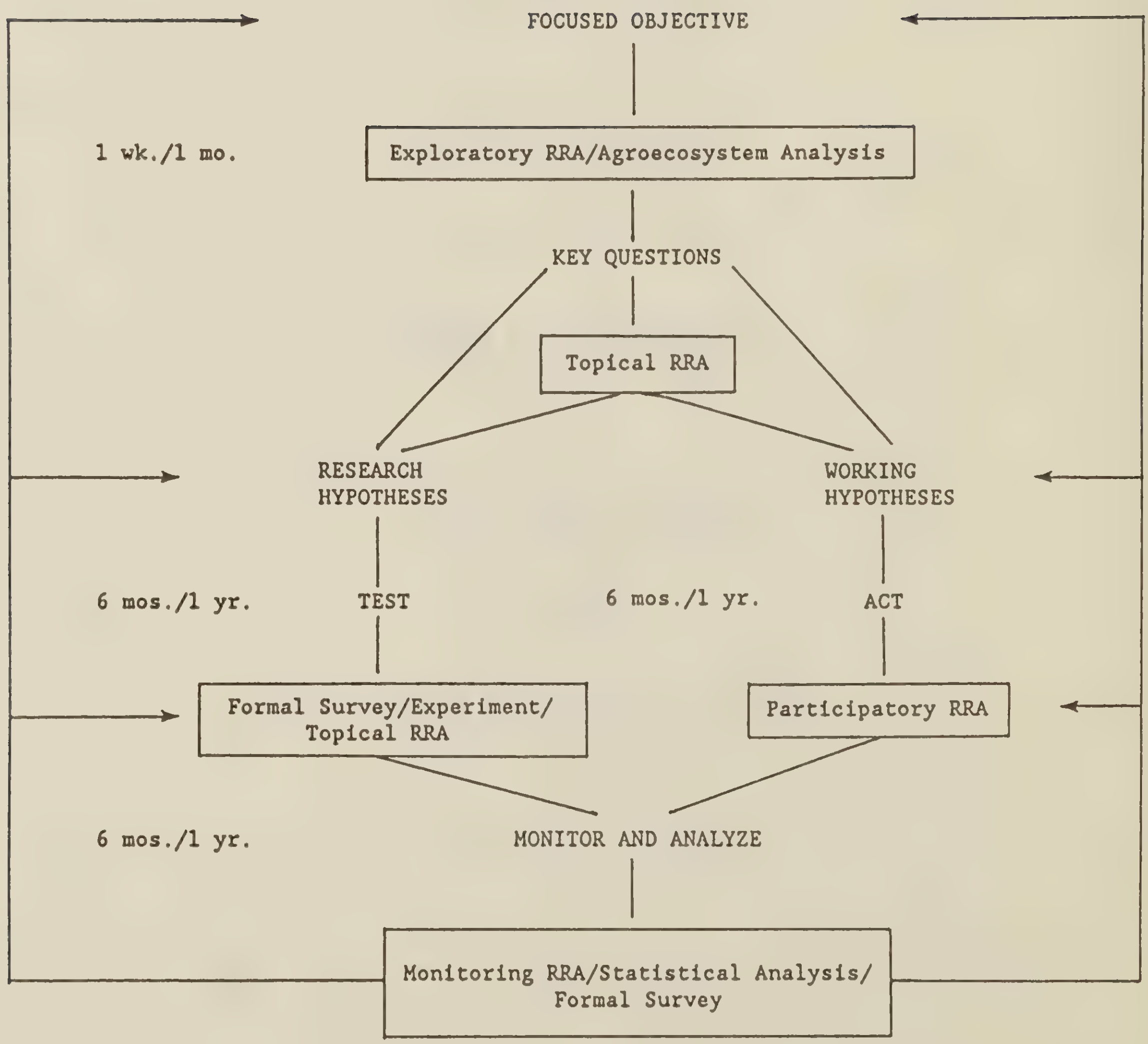


Figure 9. **Model for project design and implementation which combines the use of Rapid Rural Appraisal and formal analysis survey (Conway and McCracken, 1988).**

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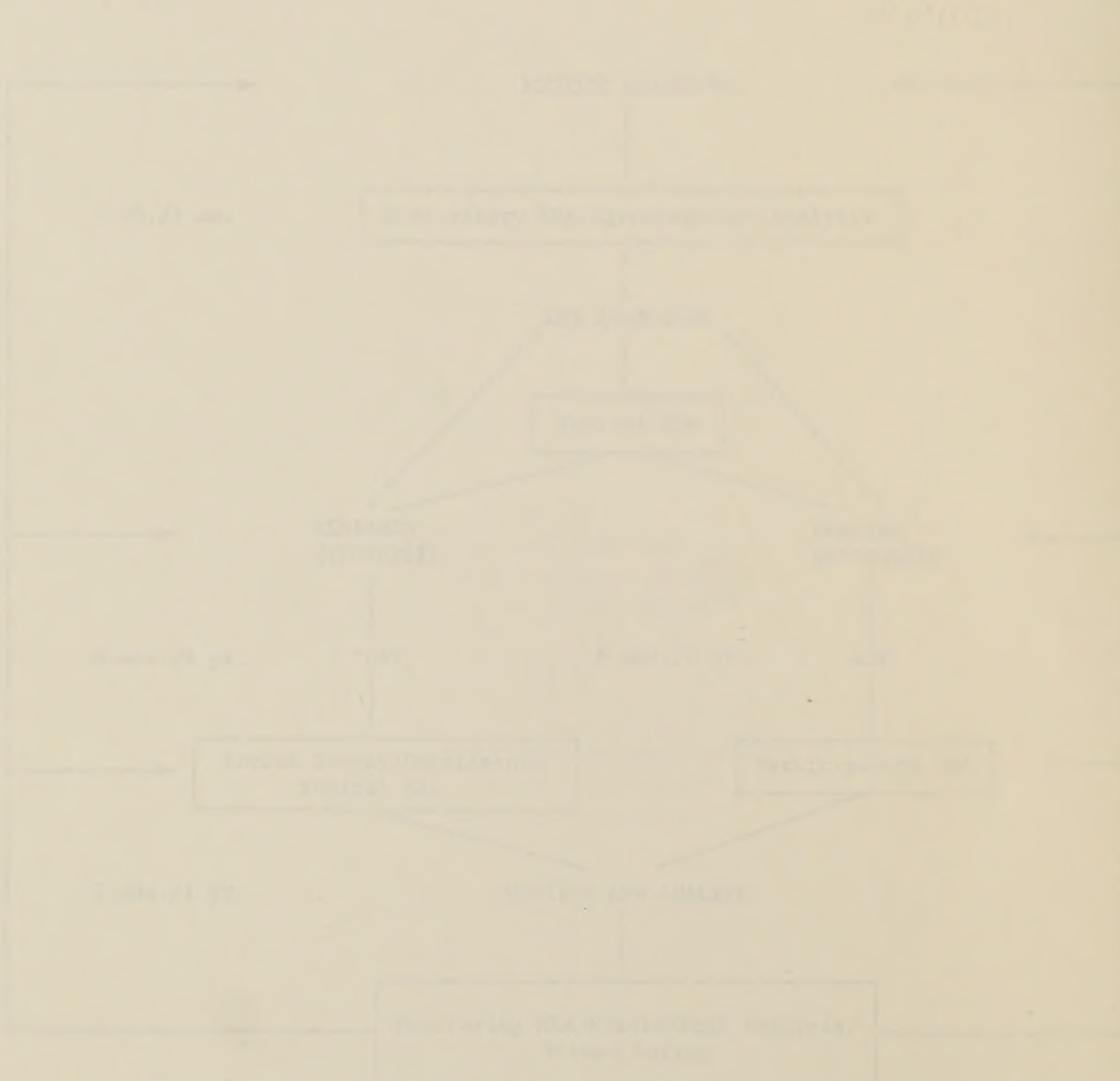

Figure 8. Model for project design and implementation which combines the use of Rapid Rural Appraisal and formal [illegible] survey [illegible]